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REGULAR PAPER

Floristic and structural vegetation typology of bonobo habitats in a forest-savanna mosaic (Bolobo Territory, D.R.Congo)

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Background and aims – Forest-savanna mosaics are some of the very diverse habitat types of the Congo Basin; multiple factors influence their dynamics such as climatic and edaphic conditions, animal dispersion, and anthropogenic activities. Presently, few studies have described this type of habitat, despite their important role in biodiversity conservation and their fragmentation. This study identified and described the floristic and structural composition of eight vegetation types of a long-term study site for bonobos in a forest-savanna mosaic of Bolobo Territory in the southwestern Congo Basin, Democratic Republic of the Congo (DRC).
Methods – We surveyed trees, lianas and terrestrial herbaceous vegetation in 51 sampling units using a nested plot sampling, totaling 12.75 ha for trees with diameter at breast height (1.30 m above ground level, dbh) $\geq$ 30 cm, 5.1 ha for tree species with 10 cm $\leq$ dbh $<$ 30 cm, and 0.02 ha for herbaceous vegetation, seedlings and saplings. First, detrended correspondence analysis of floristic data allowed the discrimination of seasonally inundated forests from *terra firma* forests. Then, structural data were analyzed to discriminate five *terra firma* forest types using hierarchical cluster analysis.
Key results – In this survey, 146 trees, 50 lianas and 42 herbaceous species were identified. Eight vegetation types were characterized. Each vegetation type was described in terms of structure (trees and lianas densities, basal areas, herbaceous vegetation densities) and floristic characteristics (species diversity, importance value index of tree species).
Conclusions – Some characteristics of vegetation types were particularly relevant to discuss (1) the forest-savanna dynamics and the important role of *Pentaclethra eetveldeana* in the plant succession, and (2) the effects of anthropogenic activities on different vegetation types

Key words – Africa, bonobo, Congo Basin, floristic composition, forest-savanna mosaic, forest structure, hierarchical cluster analysis, *Pan paniscus*, vegetation types.

INTRODUCTION

The Congo Basin comprises the second largest tropical rainforest area in the world, covering 200 million ha (Mayaux et al. 1998) and is home to a rich and diverse ecosystem including several endemic species of flora and fauna. A great diversity of vegetation types can be found in these forests, caused by various climatic and edaphic conditions, creating a variety of floristic compositions and forest structures (Mayaux et al. 1997, De Wasseige 2012). Among these habitats, the forest-savanna mosaic is a particular biotope that is commonly defined as a transition zone between savanna and forest (Mayaux et al. 1997, White & Edwards 2000). Previous studies have shown the influence of variations in paleoclimate, edaphic conditions and anthropogenic activities on the origin of the forest-savanna mosaic (De Foresta 1990, Schwartz et al. 1990, 1996). Forest-savanna mosaics are mostly present in the northern and southern parts of the Congo Basin (Mayaux et al. 2004). Floristic and phytogeographic studies have described plant species associations observed in several forest-savanna mosaics, e.g. in the Republic of Congo (Koechlin 1961) or in the Democratic Republic of the Congo (DRC) (Duvigneaud 1949, Devred 1957, Peeters 1965, Lubini 2001).They revealed a transition occurs between the guineo-congolese and sudanian regions in the northern Congo Basin and between the guineo-congolese and zambesian regions to the south. Other studies have been based on forest structure combined with floristic composition. Indeed, a 3D spatial arrangement of plant species (trees, lianas, shrub and herbs) can be considered either horizontally (e.g. density, diameter size distribution), or vertically (e.g. height, canopy opening) and also by its dynamics (Oldeman 1974, 1990). Vegetation structure vary throughout time and space (Spies 1998), illustrating perhaps disturbance (Palla et al. 2011) or plant succession (De Foresta 1990). For these reasons, structural analysis is particularly relevant in the context of a forest-savanna mosaic where forest and savanna expansion depend on climatic and edaphic conditions (e.g. rainfall, soil nutrients composition, etc.), anthropogenic activities (e.g. savanna burning, slash-and-burn agriculture, logging, etc.), or on seed dispersal by animals (e.g. elephant-dependent trees, the presence of frugivorous species, etc.). Frugivorous species play an important role in seed dispersal for the majority of woody species in tropical forests and is influenced by the spatial and temporal availability of food (Hladik & Hladik 1967, 1969, McKey 1975, Howe & Smallwood 1982). The role of great apes is particularly important through their large body size and the diversity of their diet (Wrangham et al. 1994, Lambert 1999, Poulsen et al. 2001, Beaune et al. 2013a, 2013b), in spite of their endangered status (Chapman & Chapman 1995, Muller-Landau 2007, Wright et al. 2007). Bonobo (*Pan paniscus*) is a threatened species endemic of Democratic Republic of the Congo and is not sympatric with chimpanzees (*Pan troglodytes*) and gorillas (*Gorilla gorilla* and *G. beringei*). At the distribution area scale, fragmentation and human proximity have been found as the best predictors to explain bonobo range, with negative influence on their presence (Hickey et al. 2013). The southwestern part of their distribution range is located in a forest-savanna mosaic, a minority habitat type in terms of surface for this species (IUCN & ICCN 2012, Thompson 2002). In this region, bonobo density is quite similar to other sites in continuous forests (Serckx et al. 2014, Fruth et al. 2008). Local people, a Teke ethnic group, respect a traditional taboo on bonobos (Narat et al. 2015a), observed in some others areas where the human traditions have a positive influence on bonobo presence (Thompson et al. 2008). Thus, human context and habitat nature in the southwestern part of bonobo range, despite its fragmented conformation, seem to be beneficial for bonobo presence. The few recent studies that have been conducted in this area (e.g. Inogwabini et al. 2008, Serckx et al. 2014) involved assigning habitat names based on typologies (Evrard 1968, White & Edwards 2000) without addressing plant species composition and structure in relation to habitats.

In this study, we propose to characterize vegetation types of a long-term study site for bonobos in a forest-savanna mosaic located in the southwestern part of the Congo Basin, in Bolobo Territory, 300 km north of Kinshasa. Eight vegetation types were defined using both floristic and structural data to provide more specific baseline data on the nature of the forest-savanna mosaic. Major characteristics such as densities of particular plant species and forest structure were examined in relation to plant pioneer processes and human activities, to analyze the complex forest-savanna dynamics.

MATERIALS AND METHODS

Study site

The present study was conducted in the Lefiri and Manzano forests, associated with Embirima village (2°34′S 16°22′E), Bolobo Territory, DRC (fig. 1). In 2010, in collaboration with the Congolese NGO Mbou-Mon-Tour and the National Museum of Natural History, Paris, France, a long term bonobo study was initiated by VN in the Manzano forest (Narat et al. 2015b), which is a part of a community-based conservation area (Narat et al. 2015a).

This study site includes 224 km^2 of forest-savanna mosaic (58% forest, 42% savanna) with an elevation of 332–557 m (source: ASTER data, 30 m resolution). Temperature and rainfall were measured from May 2012 to April 2014 in the traditional farm of Mamouene, located in savanna (fig. 1). The mean annual rainfall was 1957 mm with mean temperature at 7:00 am of 22.6°C (SD ± 0.88°C; range: 20.5–23.7°C). The local climate features a long dry season from May to August and a long rainy season in November and December, with annual variations (e.g. rainfall in November and December 2012 = 845 mm; in November and December 2013 =384 mm).

Data collection

We used a nested plot sampling method to survey the floristic composition and structure of vegetation types within a 50 m × 50 m sampling unit. The plot locations were determined by a random stratified sampling method, using remote sensing, and performed with ENVI software version 4.5 (Exelis Visual Information Solutions, Boulder, Colorado).

A Landsat 7 image (ETM+, 12/05/2002, 30 m resolution) was resized to focus on the study site (2°33′55″–2°41′33″S 16°17′59″–16°26′24″E). Principal component analysis (PCA) was performed to condense spectral information to a few bands. Unsupervised classification by the K-Means method (10 iterations) was applied on the first three PCA neo-canals (representing 96.8% of variability in the data) to discriminate ten spectral classes (five forest and five savanna classes) (fig. 1). A total of 51 plots were randomly placed in the five forest classes, proportionally to the extent of each class, outside a 150 m buffer zone around the edge between forest and savanna (fig. 1). In addition, to characterize forest edge and savanna, two plots were placed in edge forest vegetation, two plots in edge savanna vegetation and two plots were placed within two savanna patches at 300 m from the edge.

We used nested strip widths of 20 m and 50 m to identify, count and measure stems of different size classes and life forms within each plot using the protocol described in Bortolamiol et al. (2014) adapted from Potts et al. (2009). Inside large-size plots (50 × 50 m), all trees with diameter at breast height (dbh: 1.3 m above ground) greater than 30 cm and all lianas with dbh greater than 10 cm were identified and measured (dbh measured with dbh-meter and height estimated). Within medium-size plots (20 × 50 m), all trees with dbh between 10 cm and 30 cm and all lianas were identified and measured. In each large-size plot, four small-size plots (1 m × 1 m) were located 5 m from the plot middle line, alternatively on the left and right sides and at 10 m intervals. These were used to identify and count herbaceous species and to count seedlings and saplings (woody species < 1 m) without identification. Finally, each large-size plot contained one medium-size plot and four small-size plots.

Each plot was also described by the dominant vegetation type represented. Vegetation types used by Inogwabini et al. (2008) were assigned for a larger scale study (Lac Tumba-Lac Mai Ndombe landscape, approx. 80,000 km^2) using the typology proposed by White & Edwards (2000). Because of the smaller scale of this study, we combined vegetation types from this typology with descriptive factors such as canopy opening and dominant species (White & Edwards 2000). Thus, the six vegetation types used here were: (1) mixed *terra firma* forest with open canopy, (2) mixed *terra firma* forest with closed canopy, (3) seasonally inundated mixed forest, (4) seasonally inundated forest with *Gilbertiodendron dewevrei*, (5) edge forest, and (6) savanna.

Between February and April 2013, 51 plots (45 in forest, six in savanna) were inventoried by FP and two field assistants totaling 12.75 ha for trees with dbh ≥ 30 cm (51 large-size plots), 5.1 ha for trees with 10 cm ≤ dbh < 30 cm (51 medium-size plots) and 0.02 ha for herbaceous vegetation, seedlings and saplings (51 × 4 small-size plots). Trees and lianas were recorded using local names; herbaria vouchers were collected in duplicate when possible during vegetation census and by opportunistic collections. These were identified with the assistance of CLA at the herbarium of National Institute for Agronomic Studies and Research (INERA)/ University of Kinshasa (UNIKIN), Kinshasa and with the assistance of AH at the National Museum of Natural History, Paris. Herbaria samples were deposited at the INERA/UNIKIN herbarium (IUK), Kinshasa, DRC and at the ethnobotanical herbarium of the National Museum of Natural History (PAT) in Paris, France. Scientific names of plants are following The Plant List (2013) nomenclature.

Data analyses

Multivariate analysis was conducted to characterize vegetation types based on floristic and structural data. The first step was to discriminate vegetation types using floristic and struc-

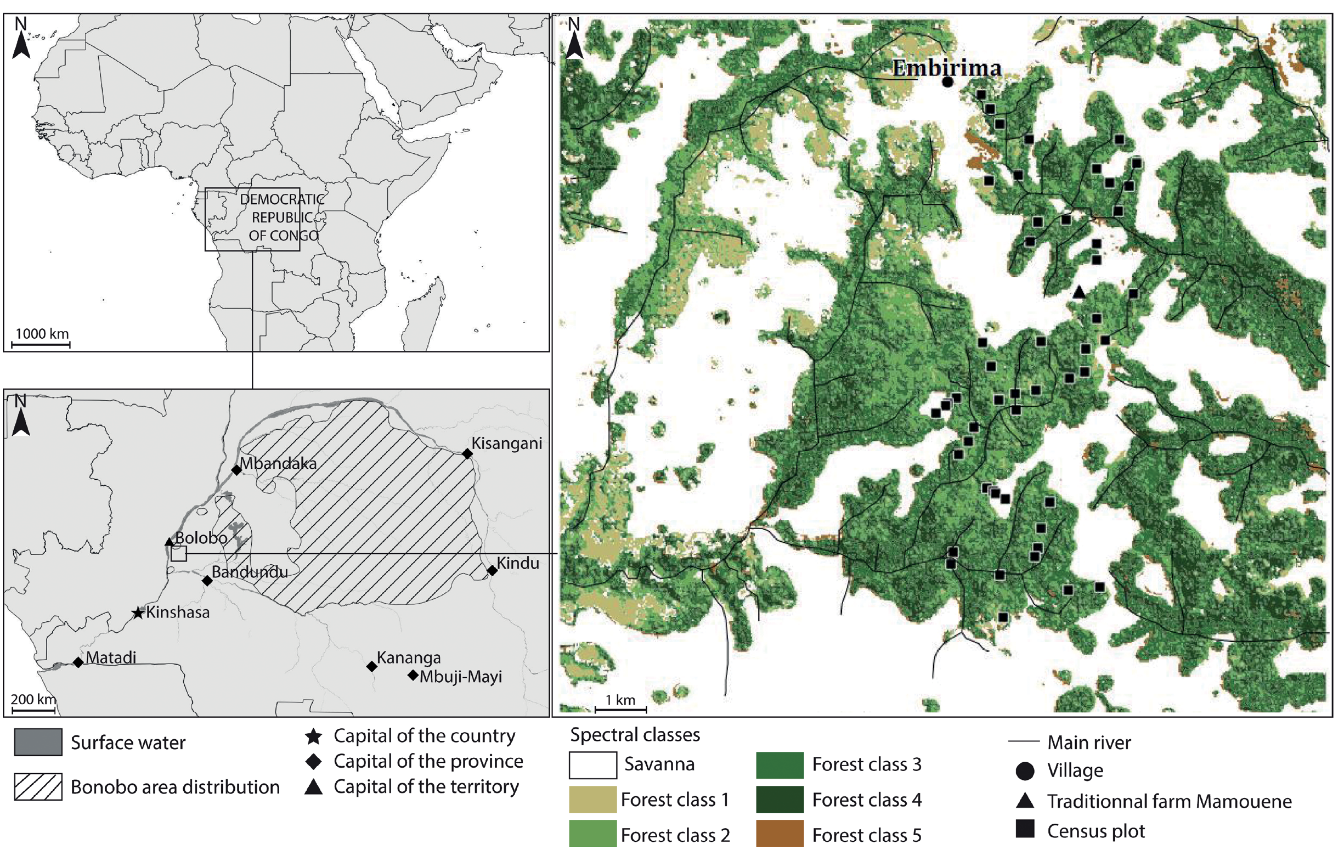

Figure 1 – Vicinity maps of the study site and results of spectral unsupervised classification performed on a Landsat 7 image (ETM+, 12 May 2002, 30 m resolution) and locations of the randomly stratified sample plots

Table 1 – Variables used for multivariate analysis of *terra firma* plots.
Variables are based on stem number of the several vegetative elements recorded during vegetation census.

N°	vegetative element	variable description	variable name
1	herbaceous species	abundance of Marantaceae species	NbMRT
2	herbaceous species	abundance of Zingiberaceae species (genus *Aframomum*)	NbZIN
3	herbaceous species	abundance of Poaceae species (essentially *Olyra latifolia*)	NbPOA
4	woody regeneration	abundance of seedlings	NbSEE
5	woody regeneration	abundance of saplings	NbSAP
6	liana	abundance of lianas with dbh < 10 cm	NbL010
7	tree	abundance of trees with 10 cm ≤ dbh < 30 cm	NbT1030
8	tree	abundance of trees with 30 cm ≤ dbh < 80 cm	NbT3080
9	tree	abundance of trees with dbh ≥ 80 cm	NbTsup80
10	tree	total tree abundance	NbTtot
11	tree	mean height of trees	Hm
12	tree	standard deviation of trees height	SDH

tural data. Then, each vegetation type was described by its floristic composition and structural characteristics.

First, we performed an ordination of plots using the abundances of tree and liana species in each plot. Savannas plots (n = 6) were excluded of this analysis to improve the discrimination of forest plots (n = 45).

Floristic data were analyzed using a Detrended Correspondence Analysis (DCA) (Hill & Gauch 1980) of the abundances of 127 woody species (trees and lianas) recorded within the 45 forest plots. This method was preferred because an arch effect was observed for Correspondence Analysis (Gauch 1982).

Among the vegetation types identified by the floristic ordination, *terra firma* forests contained more structural complexity and heterogeneity than other forests analyzed here; herbaceous strata often comprised a significant portion of their floristic composition (Gillet 2013). For these reasons, floristic characterization based only on trees and lianas needed to be completed by considering herbaceous strata and structural characteristics.

To discriminate vegetation types among *terra firma* forest, samples from this group were analyzed by combining multi-strata characteristics (Senterre 2005, Gillet 2013). Data sets of 12 variables for each sampling unit of *terra firma* forests (n = 32) were compiled to perform multivariate analysis (table 1).

PCA was performed on the 32 *terra firma* forest plots and the 12 variables. The PCA was complemented by hierarchical cluster analysis, using Euclidean distances between plot for the twelve variables and using Ward's method (Ward 1963), to partition the 32 plots into structural groups. The number of clusters was based on the decay of weighted mean of variance per cluster. The mean values of the 12 variables for each group were calculated and tested for significance by non-parametric analysis of variance (Kruskal-Wallis test). Pairwise Mann-Whitney tests were used to identify significant differences among structural groups.

Vegetation types defined by ordination (floristic groups) and multivariate analyses (structural groups) were analyzed to determine their floristic composition and structural characteristics.

An Importance value index (IVI) (Curtis 1959) was used to determine the overall importance of each species in each vegetation type. The IVI of one species is obtained from the relative density (*RDe*), the relative dominance (*RDo*) and the relative frequency (*RFe*) of the species using the following formulas:

$$RDe_i = N_i / N \quad (1)$$

where N_i is the number of individual of the species i and N is the number of individual of all species in the vegetation type.

$$BA = \pi \times (dbh/2)^2 \quad (2)$$

where BA is the basal area and dbh the diameter at breast height.

$$RDo_i = BA_i / BA_{tot} \quad (3)$$

where BA_i is the total basal area of the species i and BA_{tot} the total basal area of the species in the vegetation type.

$$RFe_i = P_i / P \quad (4)$$

where P_i is the number of sampling units with the species i and P the number of smapling units in the vegetation type.

$$IVI_i = RDe_i + RDo_i + RFe_i \quad (5)$$

The maximum value of IVI is 3 when the relative density, the relative dominance and the relative frequency are all equal to 1 (the species represents all the stems recorded in a vegetation type, and the species also represents the total basal area and is present within all sampling units of the type).

IVI was calculated for all tree species inventoried in the medium-size plots (dbh ≥ 10 cm) to avoid bias of under estimation of species with dbh < 30 cm which were not recorded in large-size plots. The relative density and the relative dominance of 99 species, identified by scientific names at least at genus level or vernacular names and representing 89% of records, were computed using the total density and total dominance including unidentified individuals.

Table 2 – Variables used to describe vegetation types.

N°	vegetative element	variable description	variable name	unit
1	herbaceous species	density of *Haumania liebrechtsiana*	NbHAULIE	/m^2
2	herbaceous species	density of *Sarcophrynium schweinfurthianum*	NbSARSCH	/m^2
3	herbaceous species	density of total herbaceous species	NbH	/m^2
4	woody regeneration	density of woody regeneration	NbWR	/m^2
5	liana	density of lianas	NbL	/ha
6	tree	density of trees with 10 cm ≤ dbh < 30 cm	NbT1030	/ha
7	tree	density of trees with 30 cm ≤ dbh < 80 cm	NbT3080	/ha
8	tree	density of trees with dbh ≥ 80 cm	NbTsup80	/ha
9	tree	total density of trees	NbTtot	/ha
10	tree	total basal area	BAtot	/ha
11	tree	mean height of trees with 10 cm ≤ dbh < 30 cm	Hm1030	m
12	tree	mean height of trees with dbh ≥ 30 cm	Hmsup30	m

To complete the description of vegetation types, structural variables and diversity indices were computed. Structural variables were composed of several variables used for structural analysis of *terra firma* forests associated with supplementary variables to illustrate some details of other vegetation types. Indeed, two variables were added to describe the presence of Marantaceae species more precisely in each vegetation type; in addition, the two variables related to woody regeneration were combined, the height mean variable was decomposed by tree dbh classes and total basal area was then calculated. In fact, 12 variables, expressed per surface unit, were obtained (table 2).

Finally, diversity indices and similarity coefficients were calculated for each vegetation type. Shannon's diversity index (H'; Shannon 1948) was computed for each vegetation type using the abundances of trees identified by scientific names at least at genus level or vernacular names and recorded in medium and large-size plots (n = 111) using formula (6):

$$H' = -\sum RDe_i \times \log_{10} RDe_i \quad (6)$$

where RDe_i is the relative density of the species i.

The Pielou index (E) was computed according to this formula (Pielou 1966):

$$E = H'/\log_{10} S \quad (7)$$

where S is the total number of species.

To examine floristic similarity between vegetation types, Jaccard (J) and Steinhaus (S) coefficients were computed using presence/absence or abundance data of trees identified as described above and recorded in medium and large-size plots (n = 111) with formulas (8) and (9) respectively:

$$J = a/(a + b + c) \quad (8)$$

where a is the number of species in common between two vegetation types, b the number of species found in vegetation 1 and not in vegetation 2, c the number of species found in vegetation 2 and not in vegetation 1.

$$S = 2w/(a + b) \quad (9)$$

where w is the sum of the minimum abundances of various species among vegetations, a the sum of abundances of species in vegetation 1 and b the sum of abundances in vegetation 2.

All statistical analyses were performed using R (version 3.1.3, R Core Team 2015). We specifically used the R package vegan (version 2.2-1, Oksanen et al. 2015), the function decorana for the detrended correspondence analysis, and the function vegdist for similarity coefficients; the R package cluster (version 2.0.1, Maechler et al. 2015) and the function agnes for hierarchical cluster analyses; and the R package ade4 (version 1.6-2, Dray & Dufour 2007) for principal component analysis.

RESULTS

Data sampling and botanical identification

Field sampling included the inventory of 1942 trees, 588 lianas and 3802 herbaceous plants as well as seedlings and saplings. Electronic appendix 1 lists all species recorded during the vegetation census with their density and basal area per surface unit for each vegetation type and other species collected outside the plots, totaling 146 tree species, 50 lianas and 42 herbaceous species belonging to 67 families. Among trees, lianas and herbaceous specimens recorded in sampling units (seedlings and saplings were not identified in this protocol), 76%, 67%, and 60% of records were determined at the family, genus and species levels, respectively (table 3). The representation of the species-area relationship (fig. 2), using identified tree species by genus or vernacular names (n = 107) in forest plots (n = 45), showed a diminution of the slope without reaching an asymptote; this illustrates a decrease of the number of new species encountered as more plots were surveyed but also suggests that some species are still unrecorded. Within the vegetation census, 22% of trees and lianas recorded belonged to the Euphorbiaceae (nine genera and thirteen species). Fabaceae was the second most represented family, totaling 19% of trees and lianas recorded (eighteen genera and 28 species). The third most represented families, representing 6% of recorded trees and lianas, were the Annonaceae (nine genera and fifteen species) and Olacaceae (five genera and six species).

Table 3 – Number and proportion of trees, lianas and herbaceous vegetation recorded and identified.

	Tree		Liana		Herbaceous plant		Seedling and sapling
	n	%	*n*	%	*n*	%	n
Recorded	1942		588		2510		1292
Identified							
Family level	1655	85	318	54	2327	93	/
Genus level	1606	83	318	54	1471	59	/
Species level	1453	75	250	43	1322	53	/

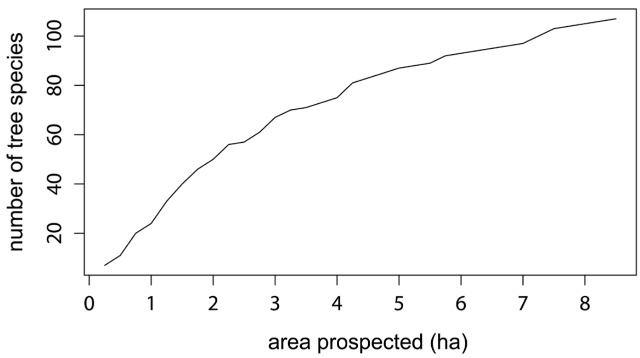

Figure 2 – Species-area relationship represented by the cumulative number of tree species recorded as a function of the area prospected (ha).

Floristic analyses were conducted on trees and lianas identified by scientific names (at least genus level, $n = 2267$) or vernacular names ($n = 172$), representing 82% of all records.

Floristic ordination by detrended correspondence analysis

Among the 45 forest plots, one plot did not contain any trees or lianas. Thus, 44 plots were analyzed by Detrended Correspondence Analysis (DCA).

The representation of plots in the plane of the two first axes of the DCA presented a gradient along axis 1 with *Gilbertiodendron* forest on the right side, seasonally inundated forests regrouped on the center and *terra firma* forests mixed

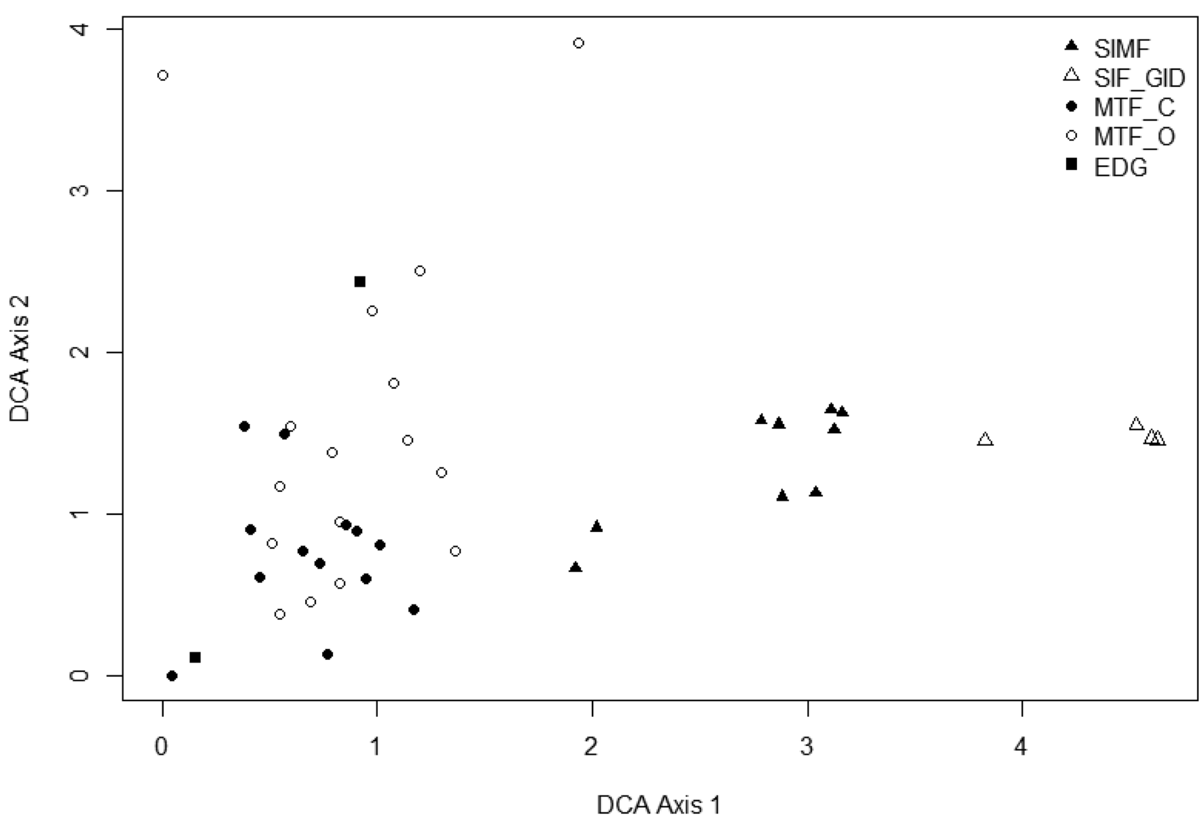

Figure 3 – Representation of plots in the plane of the two first axes of the detrended correspondence analysis. SIMF: seasonally inundated mixed forest; SIF_GID: seasonally inundated forest with *Gilbertiodendron dewevrei*; MTF_C: mixed *terra firma* forest with closed canopy; MTF_O: mixed *terra firma* forest with open canopy; EDG: forest edge.

on the left side with greater amplitude on axis 2 (fig. 3). Thus, the two seasonally inundated forest types seemed floristically identifiable contrary to *terra firma* forests. Therefore, further analyses had to be done to discriminate and characterize *terra firma* forests in more detail.

Multivariate analysis of *terra firma* forests

PCA was performed on 32 *terra firma* forest plots and the 12 structural variables. The correlation circle of the 12 variables used in the PCA showed three groups of variables (fig. 4). The first group, composed by the total tree density (NbTtot), the density of lianas and the density of trees with small dbh (10 cm ≤ dbh < 30cm), explained the first axis, and was negatively correlated with Zingiberaceae density (NbZIN). The second axis was explained by the two height variables (Hm and SDH), was positively correlated with Marantaceae density and was negatively correlated with density of woody regeneration (NbSEE and NbSAP). Densities of larger trees (NbT3080 and NbTsup80) were positively correlated and stood between the two axes; large trees were found in plots with a high density of trees (first axis) and a high canopy (second axis).

The dendrogram of hierarchical cluster analysis suggested the 32 terra firma forest plots could be divided into five groups, or structural groups (fig. 5). Table 4 presents mean values and standard deviations of the 12 variables for each cluster with values per m^2 for variables calculated from small-size plots or per ha for variables calculated from medium and large-size plots.

Using the mean values of each variable, *terra firma* clusters could be described as follows:

Cluster 1: represented by two plots characterized by the lowest densities of lianas and trees (whatever dbh class considered) and the highest density of woody regeneration.

Cluster 2: represented by 14 plots where the understorey is characterized by the lowest woody regeneration value and a

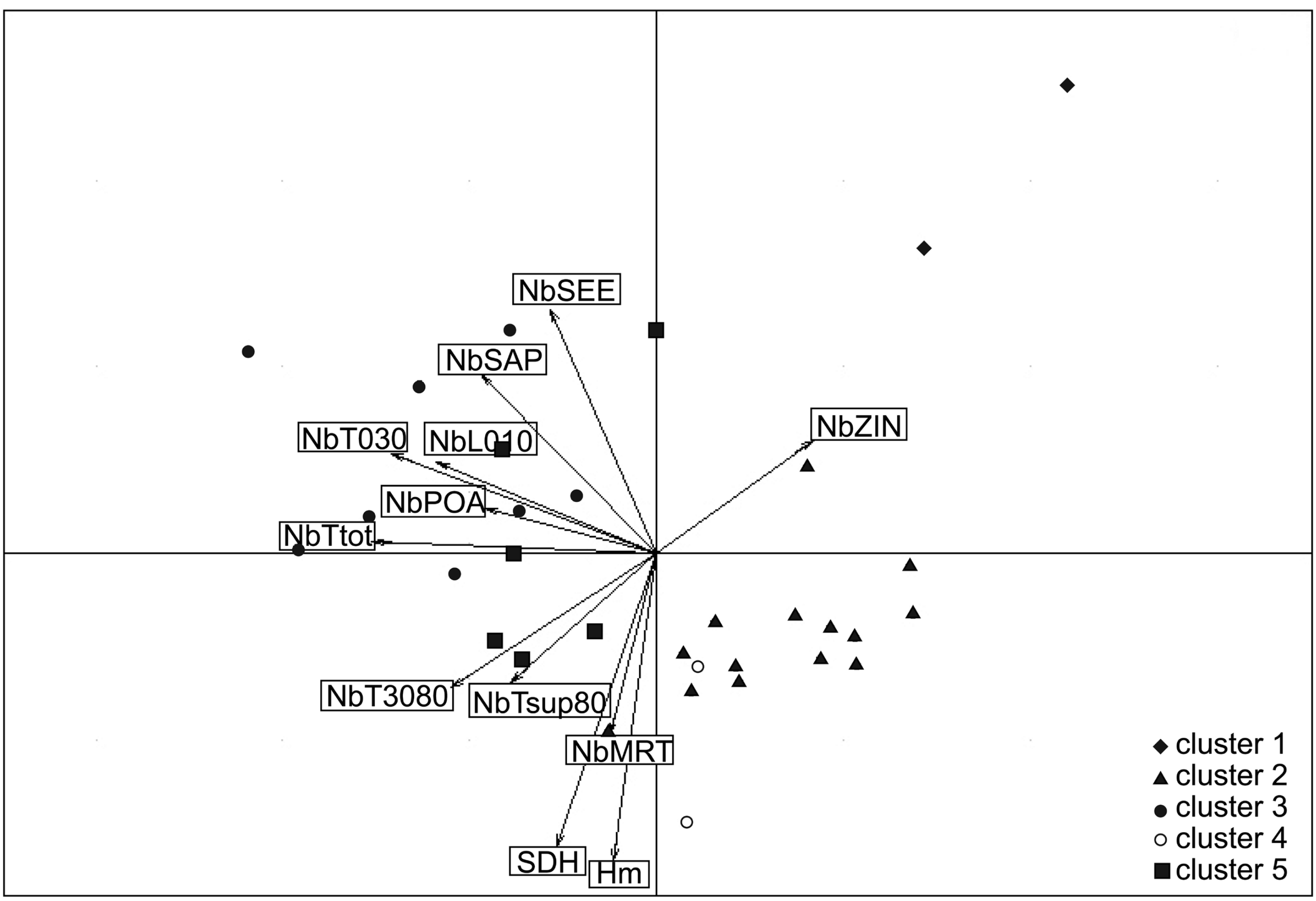

Figure 4 – Representation of structural variables and plots in the plane of the two first axes of the principal component analysis. Variables contribution (%): NbMRT axis 1 = 0.59, axis 2 = 8.85; NbZIN axis 1 = 6.58, axis 2 = 3.44; NbPOA axis 1 = 7.89, axis 2 = 0.55; NbSEE axis 1 = 3.00, axis 2 = 15.98; NbSAP axis 1 = 8.24, axis 2 = 8.63; NbL010 axis 1 = 12.95, axis 2 = 2.26; NbT1030 axis 1 = 18.81, axis 2 = 2.69; NbT3080 axis 1 = 11.37, axis 2 = 4.81; NbTsup80 axis 1 = 5.68, axis 2 = 4.48; NbTtot axis 1 = 21.70, axis 2 = 0.04; Hm axis 1 = 0.49, axis 2 = 25.34; SDH axis 1 = 2.69, axis 2 = 22.92. NbMRT: abundance of Marantaceae species; NbZIN: abundance of Zingiberaceae species (genus *Aframomum*); NbPOA: abundance of Poaceae species (essentially *Olyra latifolia*); NbSEE: abundance of seedling; NbSAP: abundance of saplings; NbL010: abundance of lianas with dbh < 10 cm; NbT030: abundance of trees with 10 cm ≤ dbh < 30 cm; NbT3080: abundance of trees with 30 cm ≤ dbh < 80 cm; NbTsup80: abundance of trees with dbh ≥ 80 cm; NbTtot: total tree abundance; Hm: mean trees height; SDH: standard deviation of trees height.

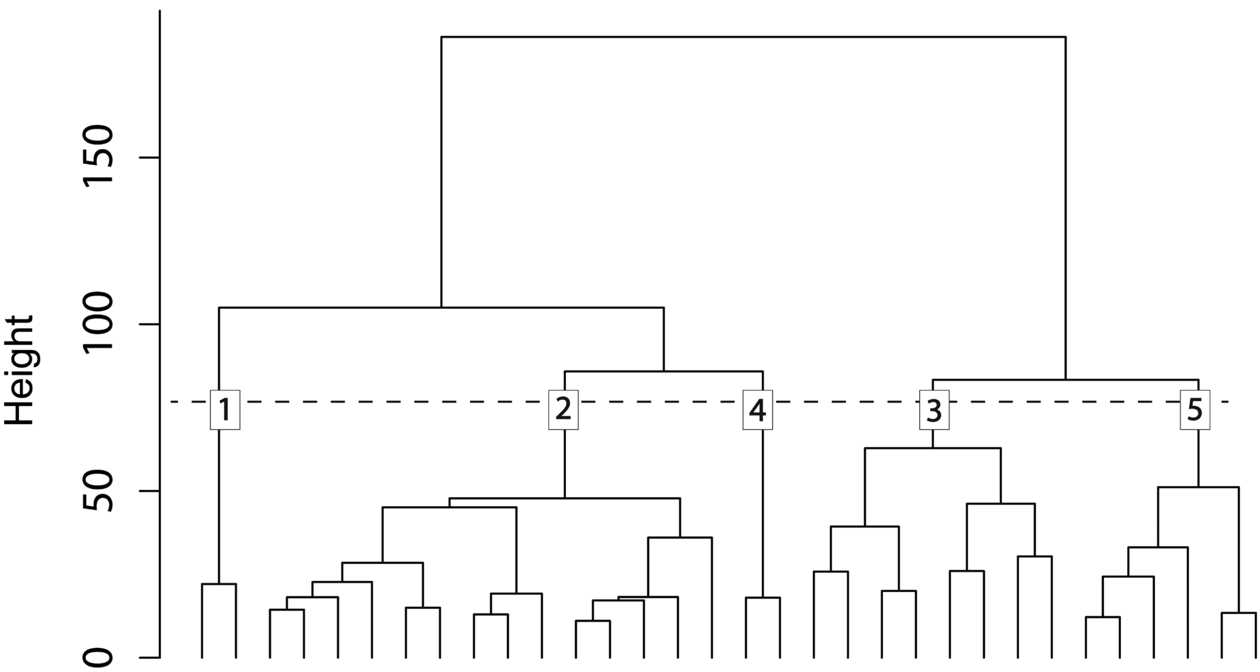

Figure 5 – Dendrogram of the hierarchical cluster analysis of *terra firma* forest plots. The dotted line represents where the dendrogram was cut.

Table 4 – Value for the twelve variables (mean ± SD) of each cluster of *terra firma* forest (number of plots).
Different letters between clusters indicate significant differences according to Mann-Whitney tests; NS = non-significant for the Kruskal-Wallis test. NbMRT: abundance of Marantaceae species; NbZIN: abundance of Zingiberaceae species (genus *Aframomum*); NbPOA: abundance of Poaceae species (essentially *Olyra latifolia*); NbSEE: abundance of seedlings; NbSAP: abundance of saplings; NbL010: abundance of lianas with dbh < 10 cm; NbT1030: abundance of trees with 10 cm ≤ dbh < 30 cm; NbT3080: abundance of trees with 30 cm ≤ dbh < 80 cm; NbTsup80: abundance of trees with dbh ≥ 80 cm; NbTtot: total tree abundance; Hm: mean trees height; SDH: standard deviation of trees height.

Variables	Unit	Cluster 1 (2)	Cluster 2 (14)	Cluster 3 (8)	Cluster 4 (2)	Cluster 5 (6)	Kruskal-Wallis test
NbMRT	/m²	0.8 ± 0	3.0 ± 1.9	3.3 ± 3.0	14.3 ± 0.4	5.4 ± 3.8	NS
NbZIN	/m²	2.0 ± 2.8	0.6 ± 1.2	0.1 ± 0.3	0.3 ± 0.4	0.2 ± 0.4	NS
NbPOA	/m²	0	0	2.3 ± 3.3	0	0.2 ± 0.5	NS
NbSEE	/m²	13.0 ± 1.1 ab	2.4 ± 2.3 a	10.4 ± 2.0 b	2.6 ± 2.3 ab	3.4 ± 1.7 ab	< 0.001
NbSAP	/m²	0.4 ± 0.5 ab	0.1 ± 0.2 a	2.5 ± 1.8 b	0.1 ± 0.2 ab	0.9 ± 1.0 ab	< 0.001
NbL010	/ha	5.0 ± 7.1 ab	32.9 ± 35.4 a	122.5 ± 28.7 b	50.0 ± 70.7 ab	118.3 ± 50.8 ab	< 0.001
NbT1030	/ha	35.0 ± 49.5 ab	73.6 ± 45.5 a	326.3 ± 115.6 b	130.0 ± 14.1 ab	323.3 ± 49.7 b	< 0.001
NbT3080	/ha	0	63.4 ± 24.1	94.5 ± 15.6	50.0 ± 2.8	78.7 ± 32.9	NS
NbTsup80	/ha	0	3.4 ± 3.8	5.5 ± 4.8	10.0 ± 2.8	4.0 ± 5.1	NS
NbTtot	/ha	35.0 ± 49.5 ab	140.4 ± 61.3 a	426.3 ± 113.4 b	190.0 ± 8.5 ab	406.0 ± 33.5 b	< 0.001
Hm	m	4.6 ± 6.6	22.2 ± 3.5	19.8 ± 2.9	22.5 ± 3.2	17.1 ± 3.6	NS
SDH	m	0.7 ± 1.0	7.6 ± 1.7	7.0 ± 1.8	8.1 ± 3.1	7.2 ± 1.4	NS

medium density of Marantaceae. Woody strata contain few lianas and trees with small dbh but the density of trees with dbh ≥ 30 cm is medium.

Cluster 3: represented by eight plots characterized by a mixed herbaceous understorey, with Marantaceae, Zingiberaceae and Poaceae, but dominated by woody regeneration. Woody strata contain the highest liana and tree densities except for trees with dbh ≥ 80cm.

Cluster 4: represented by two plots characterized by the highest density of Marantaceae and a low density of woody regeneration. Lianas and trees densities are medium except for trees with dbh ≥ 80 cm at the highest density.

Cluster 5: represented by six plots characterized by a mixed herbaceous understorey dominated by Marantaceae and a low density of woody regeneration. Woody strata are represented by high densities of lianas and trees (whatever dbh class considered).

Mann-Whitney tests showed that the main differences were between clusters 2 and 3 (significantly different; $p < 0.001$ for five variables). Indeed, cluster 2 corresponds to *terra firma* forests with Marantaceae understorey and sparse trees (sparse forests with Marantaceae understorey or SFM) whereas cluster 3 corresponds to mixed *terra firma* forest with open understorey dominated by woody regeneration (mixed forests with open understorey or MFO). Clusters 1 and 4 resulted from the same branch of the dendrogram as cluster 2 but showed no significant differences with cluster 3 despite the low density of trees. This could be attributed to the low number of plots in each cluster (only two). In fact, these two clusters correspond to old fields or fallows (cluster 1) with open canopy forest (OF) and to old fallows or sparse forest with very dense Marantaceae understorey (SFDM; cluster 4). Cluster 5 resulted from the same branch as cluster 3 and has tree densities significantly similar to cluster 3 but

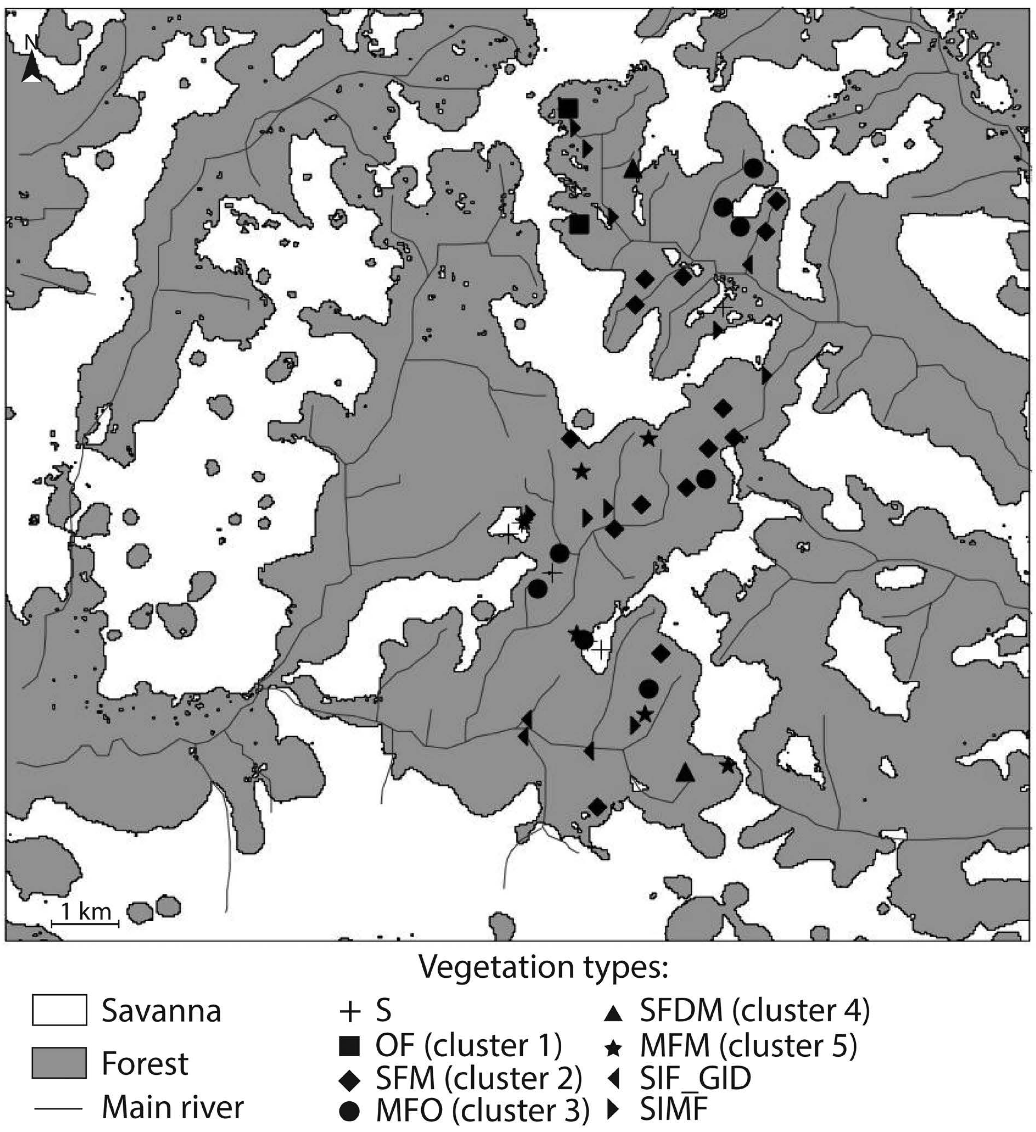

Figure 6 – Plots vegetation types determined by floristic and structural analyses. S: savanna; OF: open canopy forest; SFM: sparse forest with Marantaceae understorey; MFO: mixed forest with open understorey; SFDM: sparse forest with very dense Marantaceae understorey; MFM: mixed forest with Marantaceae understorey; SIF_GID: seasonally inundated forest with *Gilbertiodendron dewevrei*; SIMF: seasonally inundated mixed forest.

Table 5 – Value for the twelve variables (mean ± SD (min–max)) and Simpson's diversity index and Pielou index of each vegetation type.
Vegetation types: S: savanna; SIMF: seasonally inundated mixed forest; SIF_GID: seasonally inundated forest with *Gilbertiodendron dewevrei*; MFO: mixed forest with open understorey; MFM: mixed forest with Marantaceae understorey; SFM: sparse forest with Marantaceae understorey; SFDM: sparse forest with very dense Marantaceae understorey; OF: open canopy forest. Variables: NbMRT: abundance of Marantaceae species; NbZIN: abundance of Zingiberaceae species (genus *Aframomum*); NbPOA: abundance of Poaceae species (essentially *Olyra latifolia*); NbSEE: abundance of seedlings; NbSAP: abundance of saplings; NbL010: abundance of lianas with dbh < 10 cm; NbT1030: abundance of trees with 10 cm ≤ dbh < 30 cm; NbT3080: abundance of trees with 30 cm ≤ dbh < 80 cm; NbTsup80: abundance of trees with dbh ≥ 80 cm; NbTtot: total tree abundance; Hm: mean trees height; SDH: standard deviation of trees height. * mean trees height < 5 m in forest habitats are due to broken tree.

Variables	unit	S (6)	SIMF (9)	SIF_GID (4)	MFO (8)	MFM (6)	SFM (14)	SFDM (2)	OF (2)
NbHAULIE	/m²	0.00	1.86 ± 2.58 (0–6.50)	1.56 ± 2.65 (0–5.50)	0.63 ± 1.13 (0–3.00)	1.67 ± 1.99 (0–4.5)	2.16 ± 1.55 (0–4.25)	6.25 ± 0.35 (6–6.5)	0.38 ± 1.55 (0–0.75)
NbSARSCH	/m²	0.00	3.28 ± 4.68 (0–13.25)	1.81 ± 2.10 (0–3.75)	2.69 ± 2.75 (0–8)	3.25 ± 4.33 (0–9)	0.18 ± 0.67 (0–2.50)	7.88 ± 0.53 (7.5–8.25)	0.00
NbH	/m²	48.04 ± 5.98 (39.75–56.5)	8.44 ± 4.42 (3.5–16.75)	7.75 ± 4.94 (2.25–14)	6.31 ± 5.05 (0.75–13.25)	6.04 ± 3.82 (2.5–11.25)	5.89 ± 2.36 (2–10)	16.75 ± 2.12 (15.25–18.25)	14.75 ± 1.41 (13.75–15.75)
NbWR	/m²	3.96 ± 2.34 (0–5.75)	6.56 ± 3.47 (0–11)	11.06 ± 8.33 (3.5–21.75)	12.88 ± 2.78 (8–16.25)	4.29 ± 2.03 (1.25–7.25)	2.50 ± 2.36 (0.25–7.5)	2.75 ± 2.12 (1.25–4.25)	13.38 ± 0.53 (13–13.75)
NbL	/ha	3.33 ± 8.16 (0–20)	234.67 ± 167.26 (20–480)	175.00 ± 35.08 (114–192)	136.25 ± 28.54 (86–170)	130.00 ± 49.61 (62–190)	39.14 ± 39.42 (0–120)	74.00 ± 84.85 (4–124)	5.00 ± 7.07 (0–10)
NbT1030	/ha	206.67 ± 120.44 (0–340)	277.78 ± 149.23 (80–610)	325.00 ± 50.66 (290–400)	326.25 ± 115.62 (140–490)	323.33 ± 49.66 (250–360)	73.57 ± 45.5 (0–160)	130.00 ± 14.14 (120–140)	35.00 ± 49.5 (0–70)
NbT3080	/ha	1.33 ± 2.07 (0–4)	64.00 ± 21.45 (24–104)	96.00 ± 18.76 (84–124)	94.50 ± 15.56 (72–116)	78.67 ± 32.85 (24–124)	63.43 ± 24.09 (32–116)	50.00 ± 2.83 (48–52)	0.00
NbTsup80	/ha	0.00	1.33 ± 4.00 (0–12)	12.00 ± 5.66 (8–20)	5.50 ± 4.75 (0–12)	4.00 ± 5.06 (0–12)	3.43 ± 3.79 (0–12)	10.00 ± 2.83 (8–12)	0.00
NbTtot	/ha	208.00 ± 121.17 (0–340)	343.11 ± 156.31 (104–686)	433.00 ± 66.14 (396–532)	426.25 ± 107.77 (252–578)	406.00 ± 28.93 (378–440)	140.43 ± 54.93 (52–236)	190.00 ± 8.48 (184–196)	35.00 ± 49.5 (0–70)
BAtot	m² / ha	3.00 ± 1.65 (0–4.39)	16.39 ± 7.41 (5.52–32.5)	33.61 ± 5.92 (26.49–39.88)	26.38 ± 6.26 (19.37–39.05)	21.81 ± 7.96 (8.25–30.17)	15.02 ± 6.18 (7.07–30.4)	19.95 ± 4.96 (16.45–23.45)	0.95 ± 1.34 (0–1.9)
Hm1030*	m	4.81 ± 1.76 (2–12)	11.74 ± 4.99 (3–30)	14.32 ± 4.61 (1–25)	14.85 ± 5.15 (5–30)	12.37 ± 4.81 (6–25)	13.87 ± 5.77 (4–30)	15.50 ± 6.15 (6–30)	9.29 ± 1.49 (8–12)
Hmsup30*	m	8.50 ± 4.95 (5–12)	23.99 ± 7.21 (4–40)	27.36 ± 5.02 (10–38)	25.30 ± 5.99 (6–40)	25.08 ± 5.74 (5–40)	26.21 ± 6.66 (4–40)	28.50 ± 5.59 (20–40)	0.00
H'		0.42	1.18	0.85	1.26	1.43	1.48	1.14	0.18
E		0.20	0.54	0.46	0.61	0.70	0.71	0.52	0.09

Table 6 – Floristic similarity between vegetation types for trees ≥ 10 cm measured by Jaccard's coefficient (above the diagonal) and Steinhaus's coefficient (below the diagonal).
Highest values are in bold. S: savanna; SIMF: seasonally inundated mixed forest; SIF_GID: seasonally inundated forest with *Gilbertiodendron dewevrei*; MFO: mixed forest with open understorey; MFM: mixed forest with Marantaceae understorey; SFM: sparse forest with Marantaceae understorey; SFDM: sparse forest with very dense Marantaceae understorey; OF: open canopy forest.

	S	SIMF	SIF_GID	MFO	MFM	SFM	SFDM	OF
S	1	0.00	0.04	0.00	0.02	0.02	0.00	0.00
SIMF	0.02	1	0.27	0.31	0.35	0.37	0.17	0.00
SIM_GID	0.00	0.24	1	0.13	0.16	0.15	0.11	0.04
MFO	0.01	0.22	0.06	1	**0.55**	0.49	0.34	0.00
MFM	0.02	0.26	0.10	**0.59**	1	0.50	0.30	0.02
SFM	0.02	0.28	0.11	0.44	0.46	1	0.24	0.02
SFDM	0.03	0.12	0.07	0.17	0.23	0.23	1	0.00
OF	0.00	0.00	0.01	0.00	0.04	0.01	0.00	1

with a lower density of woody regeneration and a higher Marantaceae density. This cluster appears as mixed *terra firma* forest with Marantaceae understorey with high tree density (Mixed forest with Marantaceae understorey or MFM).

The floristic ordination of all forest plots and the multivariate analysis of *terra firma* forest plots led to discriminate seven forest types (fig. 6): seasonally inundated mixed forest, seasonally inundated forest with G*ilbertiodendron dewevrei*, mixed forest with open understorey, mixed forest with Marantaceae understorey, sparse forest with Marantaceae understorey, sparse forest with very dense Marantaceae understorey, and open canopy forest. Savannas were excluded from the previous analyses to improve the discrimination of forest vegetations; however, because savannas represent 42% of the study site, they have to be added to the list of vegetation types.

Floristic and structural description of the eight vegetation types

Here we present a description of each vegetation type using floristic data (species density, electronic appendix 1; basal areas, electronic appendix 2; Importance Value Index, electronic appendix 3; diversity index, table 5; similarity coefficients, table 6), and structural characteristics (table 5; distribution of dbh classes, fig. 7).

Seasonally inundated mixed forest was composed of a relatively high number of trees (334/ha, table 5) with medium dbh (67% of trees with dbh ≤ 30 cm, fig. 7) resulting with a relatively low total basal area (16.39 m^2/ha). Only two species represented more than 10% of trees with dbh ≥ 10cm in terms of density and dominance, *Gymnanthes inopinata* and *Santiria trimera*, showing a relatively high diversity of species (H'=1.18, total number of tree species = 47). Lianas were abundant (235 lianas/ha) and the understorey was composed of a medium-density of woody regeneration, Marantaceae species dominated by non-lianescent species and other herbaceous species.

Seasonally inundated forest with *Gilbertiodendron dewevrei* presented the highest total tree density (433 stems/ha) and basal area (33 m^2/ha), with an over-representation of trees with 40 cm ≤ dbh < 50 cm and the highest density of trees with dbh ≥ 80cm (12 stems/ha). Despite the high relative dominance value of *Gilbertiodendron dewevrei*, representing approximately 70% of total basal area, its rather low relative density (0.32%) and the relatively high diversity index (H' = 0.85) showed that other species with smaller dimensions shared this vegetation. The other species that was found in all sampling units was *Aptandra zenkeri*. Several species were only encountered in this vegetation (*Cleistanthus inundatus*, *Daniellia pynaertii*, *Rinorea oblongifolia*) and other species were common with SIMF (more than 25% overlap in floristic composition). Lianas were quite abundant and understorey was dominated by woody regeneration.

Mixed forest with open understorey showed the highest density of trees (426 trees/ha) and lianas (136 lianas/ha) among *terra firma* forests. The total basal area was lower than in seasonally inundated forest with *Gilbertiodendron dewevrei* despite similar tree densities, because of the smaller dimension of trees (80% of trees with dbh < 40cm). The most represented species was *Pentaclethra eetveldeana* with 97 trees/ha (trees with dbh ≥ 10 cm) and representing nearly 30% of basal area. The next most important species were *Plagiostyles africana*, *Anonidium mannii*, *Staudtia kamerunensis*, presenting densities more than twofold lower than *Pentaclethra eetveldeana*. The understorey was characterized by an abundance of woody regeneration and few Marantaceae.

Mixed forest with Marantaceae understorey was structurally quite similar to mixed forest with open understorey composed of high densities of trees (406 trees/ha) and lianas (130 lianas/ha) as well as a similar distribution of tree size to that of mixed forest with open understorey. Floristically, mixed forest with Marantaceae understorey and mixed forest with open understorey were the most similar (highest value of similarity coefficients) but more tree species were encountered in mixed forest with Marantaceae understorey and so this vegetation had a higher diversity index than in mixed forest with open understorey. Some of important species were *Plagiostyles africana*, *Sorindeia juglandifolia* and *Chaetocarpus africanus*, presenting quite similar, but low, relative dominance except for *Piptadeniastrium africanum* which represented 17% of total basal area with only 1% of stems because of the large dimension of trees encountered (*n* = 3; mean dbh = 89.3 cm ± SD 66.5). The understorey was relatively poor in woody regeneration and erect Marantaceae (*Sarcophrynium schweinfurthianum*) dominated lianescent species (*Haumania liebrechtsiana*).

Sparse forest with Marantaceae understorey presented the greatest diversity index with a tree species composition quite similar to mixed forest with Marantaceae understorey (second highest value of similarity coefficients) but with a very different structure. The tree density was lower, reaching 140 stems/ha with an under-representation of trees with dbh < 30 cm representing only 33% of trees. The understorey was the poorest in woody regeneration and *Haumania liebrechtsiana* dominated *Sarcophrynium schweinfurthianum*. The relatively low IVI, and particularly low relative frequency, showed the variability of species encountered among sampling units. *Pentaclethra eetveldeana* was the most represented species. A few species (*Celtis tessmannii*, *Klainedoxa gabonensis*, *Millettia laurentii*) had a rather high relative dominance in relation to their relative density, illustrating species with large dimensions.

Sparse forest with very dense Marantaceae understorey had a structure similar to sparse forest with Marantaceae understorey with higher abundance of *Haumania liebrechtsiana* and *Sarcophrynium schweinfurthianum* but presenting a lower diversity of tree species. Large trees, mostly *Klainedoxa gabonensis*, were associated with smaller trees belonging to species shared with the other *terra firma* forests.

Open canopy forest was clearly representing forest regrowth by its high density of woody regeneration and its abundance of small trees belonging to pioneer species (*Musanga cecropiodes* and *Trema orientalis*).

Savanna was dominated by *Hymenocardia acida*, *Maprounea africana* and *Annona senegalensis* reaching 208 trees/ha. Three species were mostly present near the forest edge (*Pentaclethra eetveldeana*, *Anthocleista* sp. and *Macaranga* sp.), illustrating forest colonization on the savanna. One sampling unit was herbaceous swampy savanna with no trees.

DISCUSSION

In the present study we characterized various vegetation types in the forest-savanna mosaic of the southwestern part of the Congo Basin in the DRC, in a long-term study site for bonobos. Our methodology, based on vegetation surveys with floristic and structural data, allowed the discrimination of eight vegetation types based on their species composition and structural characteristics. By comparing species recorded in our survey with more global studies, vegetation types seem representative of Central Africa forests. A focus on some species or vegetation types could provide elements

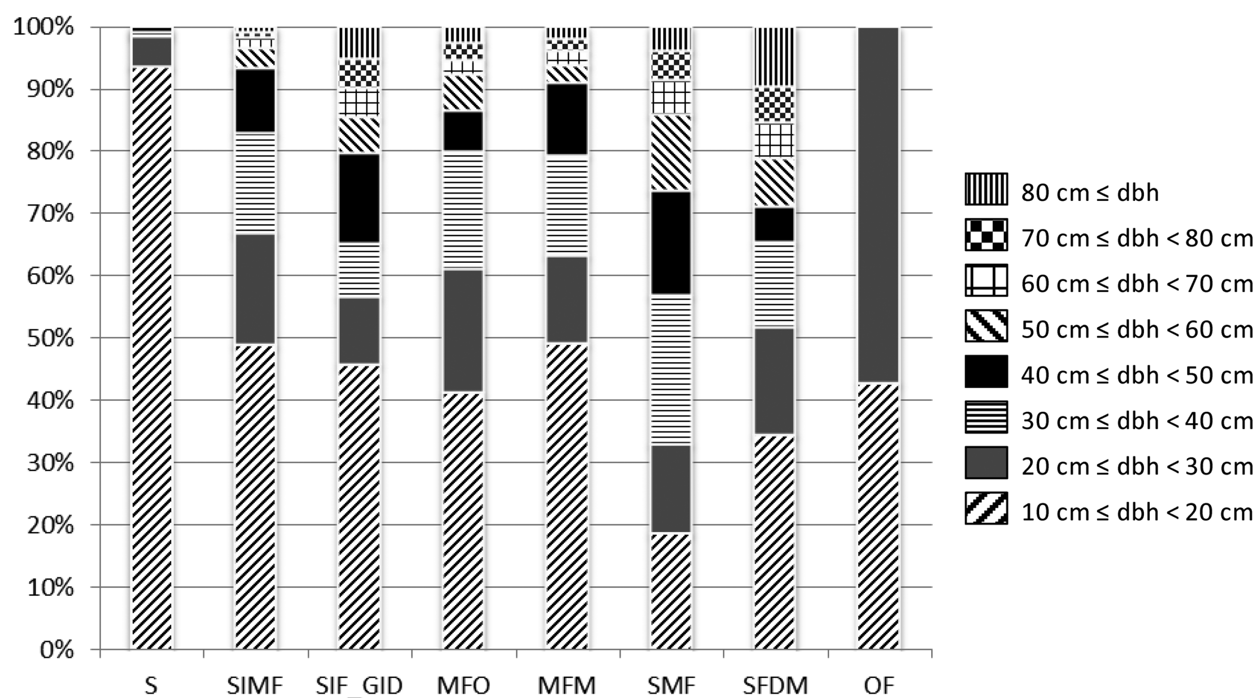

Figure 7 – Distribution of diameter at breast height (dbh) classes for each vegetation type. S: savanna; SIMF: seasonally inundated mixed forest; SIF_GID: seasonally inundated forest with *Gilbertiodendron dewevrei*; MFO: mixed forest with open understorey; MFM: mixed forest with Marantaceae understorey; SFM: sparse forest with Marantaceae understorey; SFDM: sparse forest with very dense Marantaceae understorey; OF: open canopy forest.

about factors influencing forest-savanna dynamics such as plant succession involved in forest expansion and human activities.

Methodology used to discriminate vegetation types

Our study was carried out in two principal steps to discriminate vegetation types: (1) a floristic ordination to identify floristical vegetation types; and (2) a structural classification for vegetation types which were less discriminated floristically (*terra firma* forests). Then, each vegetation type identified was described by floristic and structural characteristics.

Concerning the ordination, the use of DCA rather than CA in our study was preferred to facilitate identification of floristic groups. However, the usefulness of detrending is still debated because of variations in environmental interpretation, based on arbitrary segmentation of axis (Legendre & Legendre 1998). Since DCA was used here only to discriminate vegetation types floristically without interpreting environmental gradient, we choose DCA to avoid the arch effect in the representation of plots in the plane of the two first axes.

Concerning the classification, the structural variables used vary among studies, even in the same geographical area or forest types (e.g. Palla et al. 2011, Gillet 2013, Senterre 2005), depending on the characteristics of vegetation the authors want to highlight. The choice of variables will influence the results of classification, and so the vegetation types discriminated and their interpretation. In this study, our chosen variables are used for identification of the various components (trees, lianas, herbaceous plants).

Vegetation types representative of Central African forests

The vegetation types encountered in our study site could be set in the broader context of African tropical forests. Many species recorded are common in Central Africa: among the 110 trees identified at species level, 97 were used by Fayolle et al. (2014) to identify variations in tree species composition across tropical African forests (from Senegal to Mozambique) and 65 were characteristic of Central African forest (43 of Moist Central Africa and 22 of Wet Central Africa). Moreover, the number of tree species recorded (n = 146, including those identified at family or genus level and by vernacular name) is comparable with other studies led in DRC on similar prospected areas (e.g. Boubli et al. 2004, Serckx et al. 2014) even if some species remain unrecorded as suggested by the species-area curve (fig. 2).

However, some species were not recorded while they are characteristic of Congo Basin forests (Lebrun & Gilbert 1954) and have been recorded only 25 km away from the study site (Bastin et al. 2015) like *Scorodophleus zenkeri*. This absence suggests a variability of vegetation types at regional scale, which could be related to edaphic, climatic or anthropogenic conditions. The forest conformation could also explain these differences since the fragmentation affects plant species repartition at landscape scale (Galanes & Thomlinson 2009).

Overall, vegetation types and plant species in this forest-savanna mosaic seem to be representative of Congo Basin forests with random particularities induced by the local scale of the study.

Vegetation types reflecting forest-savanna dynamics

Among the *terra firma* forest types characterized in this study, the presence of sparse forests with Marantaceae understorey in the context of a forest-savanna mosaic could be presented based on plant species succession that is involved in forest expansion. Indeed, sparse forest with Marantaceae understorey had been interpreted as a transitional step during the colonization of savanna by forest in the Republic of Congo (De Foresta 1990) and in Gabon (White 1992, White et al. 2000). Analyzing the locations of vegetation types in our study site (fig. 6), among the four plots located close to forest edge (< 60 m), various vegetation types are present (seasonally inundated mixed forest, seasonally inundated forest with *Gilbertiodendron dewevrei*, mixed forest with open understorey, and mixed forest with Marantaceae understorey). This is obviously different from the description of the Mayombe forest-savanna mosaic where the included savannas were surrounded by sparse forest with Marantaceae understorey (De Foresta 1990) and from the plant succession in La Lopé National Park where mono-dominant forests of pioneer species (*Aucoumea klaineana)* colonized savannas and evolved into Marantaceae forest (White 1992, White et al. 2000). In our study site, the species with greatest IVI in sparse forest with Marantaceae understorey is *Pentaclethra eetveldeana*, a pioneer species that is also present in all other *terra firma* forests. Reaching a density of 2467 stems/km^2 (for trees with dbh ≥ 10 cm in all vegetation types, electronic appendix 1), *Pentaclethra eetveldeana* is the species with the highest density and its density is considerably greater than in La Lopé where it reaches 640 stems/km^2 in Marantaceae forests, and 240 stems/km^2 in closed canopy forests (Tutin et al. 1994). The density of *Pentaclethra eetveldeana* is not related to the distance from the edge (linear regression; coef = −0.0039, F = 1.33, p = 0.2553) however the mean dbh slightly increased with the distance from the edge (linear regression; coef = 0.0202, F = 8.317, p = 0.0095). *Pentaclethra eetveldeana* could play the same role in forest expansion as *Aucoumea klaineana* at La Lopé, although these two species are totally different in terms of functional traits (growth rate, dispersal, regeneration…). Moreover, among vegetation types described previously in this region at larger scale (Inogwabini et al. 2008) recolonizing *Uapaca* forests should correspond to dynamics similar to other phytogeographic areas of the Congo Basin (Lubini & Mandango 1981). In our study, *Uapaca* spp. are mostly present in seasonally inundated mixed forests (78% of *Uapaca* spp. trees with dbh ≥ 10 cm in seasonally inundated mixed forest) and not at all a dominant species (relative dominance < 10% whatever the vegetation type considered). We can expect that different pioneer processes are in action in this region, showing the importance of small scale studies to untangle the diversity in vegetation types and forest dynamics.

Pentaclethra eetveldeana appears to be an important species for the forest-savanna dynamics in our study site although further studies should be conducted to understand plant succession and factors influencing forest expansion. Indeed, the edges are involved in rather complex dynamics including those related to human activities.

Vegetation types as a consequence of human activities

Human density in our study site is relatively low (5 inhab./km^2, Narat 2014) but many traditional activities occur in the forest (Narat et al. 2012), notably shifting agriculture which is practiced traditionally using slash-and-burn technique in small areas (0.5 ha) near the forest edge. Thus, some *terra firma* forest types with lower tree density clearly illustrate disturbances both by their structure and by the presence of particular species. This is the case of open canopy forests where only two pioneer species (Swaine & Whitmore 1988) were recorded (*Musanga cecropioides* and *Trema orientalis*). As shown in Makokou, Gabon, their presence could be informative about agricultural cycles since *Musanga cecropioides* is a common forest regrowth species while *Trema orientalis* has been observed after numerous successive cultural cycles (Mitja & Hladik 1989). The location at the forest edge could influence dynamics of the forest by changing plant species composition and thus the pattern of succession. Moreover, logging activities have taken place in our study area on selected timber species, such as wenge (*Millettia laurentii*) (Greenpeace 2012; F. Pennec and V. Narat, MNHN, France, pers. obs.). The last exploitation occurred in 2012 in the southeastern part of the forest (F. Pennec and V. Narat, MNHN, France, pers. obs.) but according to local informants, logging previously occured in other locations within the forest. However, by timber selection and the location of agriculture on the edges of forests, anthropogenic activities have not impacted all forest types since *Gilbertiodendron dewevrei* forests are considered as primary forests (Gérard 1960) and illustrate an absence of major disturbance during a long period (Hart et al. 1989). Species of old growth forest are also present in *terra firma* forests such as *Parinari excelsa*, *Anonidium mannii*, *Dialium pachyphyllum*, *Strombosia* spp. but also species of regrowth forest may be present including *Musanga cecropioides*, *Myrianthus arboreus* and old regrowth forest species such as *Canarium schweinfurthii*, *Petersianthus macrocarpus* and *Pycnanthus angolensis* (Lubini & Mandango 1981).

Finally, this study provides the first baseline description of vegetation types in a forest-savanna mosaic in the southwestern part of the Congo Basin in terms of species composition and structural characteristics. These data are relevant elements for a long-term study site for bonobos in order to explore their feeding ecology, spatial repartition or social cohesiveness and to compare with other study sites. Understanding differences in plant species composition that could be linked to animal densities and feeding behaviour is important, especially for threatened species which are also keystone and umbrella species (e.g. Malenky & Wrangham 1994, Potts et al. 2009, 2011, Bortolamiol et al. 2014). Moreover, by its fragmented conformation and its floristic composition, further studies should be carried out on this site to precise the role of pioneer species in the forest-savanna dynamics.

SUPPLEMENTARY DATA

Supplementary data are available in pdf at *Plant Ecology and Evolution*, Supplementary Data Site (http://www.ingentaconnect.com/content/botbel/plecevo/supp-data), and consist of: (1) densities of trees, lianas and herbaceous species recorded during vegetation census in each vegetation type and species collected by opportunistic collection (empty cells); (2) basal area of trees, lianas species recorded during vegetation census in each vegetation type and species collected by opportunistic collection (empty cells); and (3) Importance Value Index of tree species recorded in medium size plots (20 m × 50 m, dbh ≥ 10 cm) for each vegetation type.

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