



Natural regeneration of first growth species with high socio-economic potential in forest ecosystems in the northern sector of the Léfini Reserve

Ghislain Bileri-Bakala^{1,*}, Oracle Clément Tondo Bafouiri Ntsoni^{1,2}, Mamboueni Josérald Chaîph^{1,2}, Promesse Mousda Nguimbi Tsatsa³, Victor Kimpouni^{1,2,3}, Jean Joël Loumeto¹

¹Biodiversity, Ecosystems and Environmental Management Laboratory (LBGE),

Faculty of Science and technology (FST), Marien Ngouabi University (UMNG), Republic of Congo

²National Forest Research Institute (IRF), Brazzaville, Republic of Congo

³Higher Teachers' College (ENS), Marien Ngouabi University, Republic of Congo

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Abstract

The natural regeneration of prime timber species with high economic potential is studied in the Mpo forest, in the northern sector of the Léfini reserve. Although a source of economic and self-subsistence for local residents, the natural regeneration of these forest ecosystems has received very little attention. The floristic inventory was carried out in three one-hectare quadrats, in which (i) the d^{1-30} of ligneous plants $1 \text{ cm} \leq d^{1-30} < 10 \text{ cm}$, $d^{1-30} \geq 10 \text{ cm}$ and seedlings $\geq 30 \text{ cm}$ in height were counted and measured; (ii) the degree of canopy openness, litter thickness and herbaceous cover. The inventory reveals 1208 individuals for 36 species and 20 families, i.e., 118 seedlings of height $\geq 30 \text{ cm}$; 769 individuals of $1 \text{ cm} \leq d^{1-30} < 10 \text{ cm}$ and 321 of $d^{1-30} \geq 10 \text{ cm}$. Structural parameters favor *Petersianthus macrocarpus* as dominant in the $1 \text{ cm} \leq d^{1-30} < 10 \text{ cm}$ and $d^{1-30} \geq 10 \text{ cm}$ diameter classes, in density (89 trees.ha⁻¹) and basal area (7.137 m².ha⁻¹). In contrast, *Entandrophragma* sp. dominates the seedling class ($h \geq 30 \text{ cm}$). The bioecological indices highlight a difference in the floristic composition of the compartments. Natural regeneration, dependent on light and litter thickness, is generally good. Depending on the socio-economic value of taxa with difficult natural regeneration, intervention may be necessary.

* Corresponding Author: Ghislain Bileri-Bakala ✉ ghislainbileri@gmail.com

Introduction

Globally, forests cover some 4.06 billion hectares, with tropical forests (approximately 1230 million hectares) constituting the largest forest biome (Mayaux *et al.*, 2004; FAO, 2010a). Tropical forests, which are divided into three basins - Amazonia, Borneo-Mekong and Congo in tropical Africa - encompass half of the world's biodiversity (ECOFAC, 2004; FAO, 2010b; Mille and Louppe, 2015; Mayaux *et al.*, 1998; Bergonzyni et Lanly, 2004). The forests of the Congo Basin, the second largest tropical massif, represent 10% at continental level, of which around 14% benefit from protected area status (UNESCO, 2018; Doumenge *et al.*, 2021). These ecosystems are subject to strong anthropogenic pressures such as timber exploitation and slash-and-burn agriculture, the corollaries of which affect the three compartments of biodiversity (reduction in species richness and habitats, and genetic erosion) (IUCN, 2009; WWF, 2020).

Due to their high biodiversity, these forests provide ecosystem goods and services to local residents, and therefore play an essential role in the rural economy and in the well-being of populations (FAO, 2020; Gbozé *et al.*, 2020; Lhoest *et al.*, 2020; Kimpouni *et al.*, 2021). Notwithstanding these aspects, these forests play an important role in ecological balance by sequestering carbon (UNESCO, 2018; IIFT, 2019; N'guessan *et al.*, 2019). As a result, their conservation is attracting particular attention worldwide (Ayessa *et al.*, 2022).

Around 65% of Congolese territory is covered by forests, with protected areas accounting for 11% (IUCN/PACO, 2012). These biodiversity conservation areas are characterized by a remarkable biological richness and variety of landscapes, ensuring a major ecological and socio-economic role (Olatoundji *et al.*, 2021).

The exploitation of forest species with high economic potential, which is the second cause of deforestation in Africa, impacts both genetic diversity and the regeneration capacity of certain taxa (Nguenguim *et*

al., 2015; FAO, 2020). Biodiversity data are still very patchy in Congo, and the exploitation of forest ecosystems is a source of bias in the dynamics and functioning of these ecosystems (Kimpouni *et al.*, 2020). This activity is coupled with exponential population growth, the corollary of which is urbanization, which rhymes with a reduction in vegetation cover due to the transformation of land for their well-being (Fahrig, 2003; Nguyen Van and Azomahou, 2003). African forests in general, and those of the Congo in particular, are experiencing anthropogenic destruction associated with the quest for timber and non-timber products (Kimpouni *et al.*, 2013; Tchatchou *et al.*, 2015; UNESCO, 2018).

Sustainable management of these ecosystems requires a good understanding of population dynamics (Puig, 2001; Lebourgeois *et al.*, 2002; Daïnou *et al.*, 2012; Doucet, 2024). Understanding the different phases of forest succession, and the dynamics and equilibrium of the stand, is crucial to developing strategies for the conservation and perpetuation of these habitats (Bénédet *et al.*, 2024).

The interest of this research lies in the fact that natural regeneration work often focuses on urban and peri-urban forests, to the detriment of other types, and particularly inhabited protected areas (Boyemba Bosela, 2006; Kompanyi Amisi, 2012; Kimpouni *et al.*, 2013, 2020).

The aim is to assess the natural regeneration of woody species with high economic potential in the forest of the northern sector of the Léfini reserve. Thus, the key parameters are (i) stand characterization, (ii) assessment of the natural regeneration potential of taxa, (iii) determination of the environmental factors influencing natural regeneration.

Materials and methods

Study area

The Léfini Faunal Reserve is located in south-eastern Congo and was initially created by decree no. 3671 of 26 November 1951 over an area of 400,000 ha, then expanded to 60,000 ha from 1963 by decree no.

0046/MAEEFGR-CH-CN of 7 January 1963 (IUCN/PACO, 2012). This reserve straddles the Pool and Plateaux prefectures, particularly between the sub-prefectures of Ngabé (Léfini-Sud) and Ngo (Léfini-Nord) (Hecketsweiler, 1990) (Fig. 1). The

Léfini-Nord reserve extends between latitudes 02°21'12.348" South and 3°04'10.776" South and longitudes 15°06'03.600" East and 15°46'16.824" East. The boundaries of the reserve are marked by passable roads dotted with villages and watercourses.

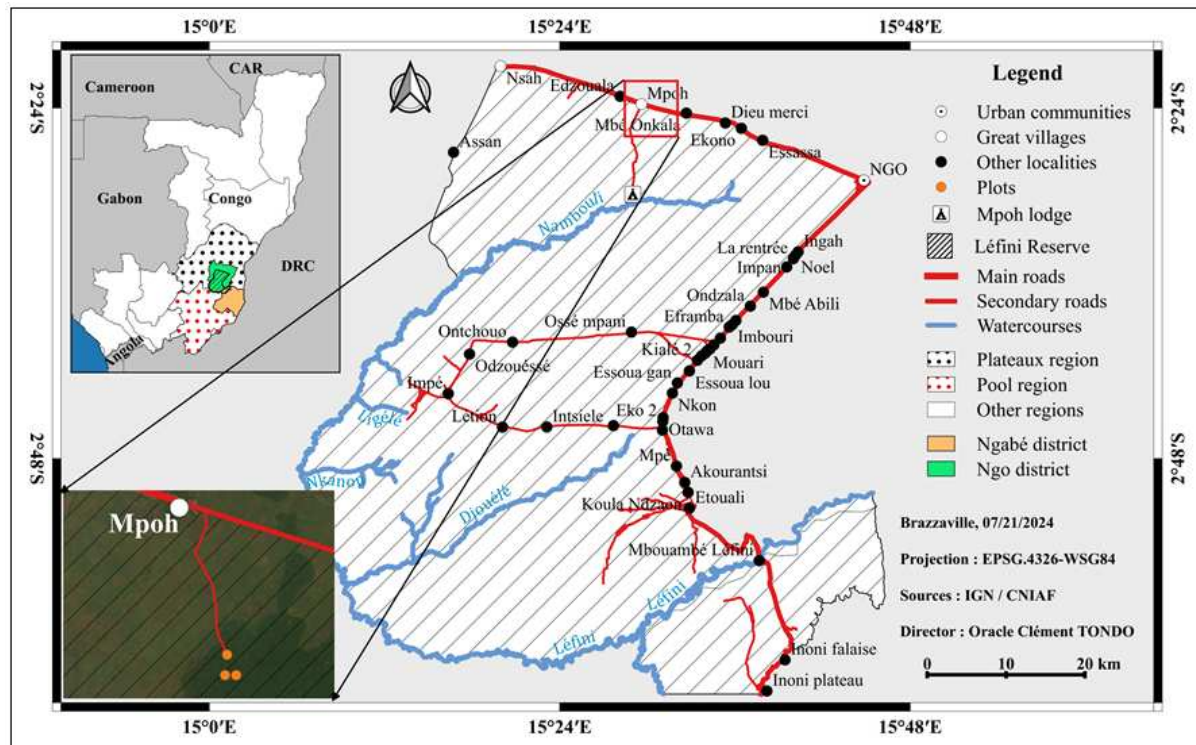


Fig. 1. Location of the Léfini reserve and floral surveys.

Climatic characteristics

Characterized by average rainfall of 1,600 to 2,000 mm/year and an average temperature of 25°C, the northern sector of the Léfini reserve has an Aw-type climate (Köppen, 1936). This climate is characterized by a dry season lasting around 1 to 3 months and mild temperatures (Vennetier, 1977).

The relatively short dry season runs from June to August (Goma-Boumba and Samba-Kimbata, 2019). The rainy season, which peaks in April and September, is characterized by heavy rainfall and high temperatures. This season, which is the longest, runs from September to May, with a slowdown in rainfall in December and January (Goma-Boumba and Samba-Kimbata, 2019).

Vegetation

The vegetation of the northern sector of the Léfini

reserve is verdant and divided into two major biomes: a forest-savannah mosaic and well-drained riparian and valley forests. The vegetation belongs to the great Guinean-Congolese floristic region of evergreen rainforest (Hecketsweiler, 1990). The savanna facies is dominant, with *Trachypogon thollonii* and *Annona senegalensis* (Makany, 1976) being the main taxa.

Geology and soils

The northern sector of the Léfini reserve is part of the Batéké plateaux, which evolve on the Batéké sandstone series (Boissezon and Gras, 1970; Denis, 1974). The geological substratum is represented by sedimentary formations of Cenozoic (Tertiary) age, of a sandstone nature where they form the polymorphous sandstone series or Batékés sandstone series. Depending on the author, the latter is either Upper Kalahari or the result of alteration of the schistosandstone system in situ.

Soils in the northern sector of the Léfini reserve are impoverished yellow ferrallitic on highland sandy-clay material (Hecketsweiler, 1990). Soils under savannahs have a slightly different morphology to those on sandy materials. The humus-rich, sandy upper horizon has a lumpy structure, generally less than 10 cm thick. The following homogeneous humus-bearing penetration horizon, slightly more clayey, is still dark in color; the structure is nuciform to polyhedral, with little coherence. From a depth of around 50 cm, the humiferous penetration by brown patches and streaks in the yellow-ochre material gives rise to a horizon of variegated appearance; the polyhedral-type structure with low to medium cohesion is here maximum for the profile, the sandy-clay texture is analogous to that of the original yellow material we find below and which remains identical to itself for several meters. Although morphologically and texturally very similar, the impoverished sandy-clay soils derived from sandy silts (soils of the Koukouya and Djambala plateaus) differ in their organic matter content from soils derived from Souenzian sandstones. In the 0-10 cm layer, these contents average 8% for the former soils and 2-3% for the latter. This more marked accumulation of organic matter in Batéké plateau soils may be attributed to the influence of altitude, with a slightly colder climate and higher rainfall (Boissezon *et al.*, 1969).

Relief and Hydrography

On a large scale, the northern sector of the Léfini reserve is made up entirely of a succession of rounded hills with fairly steep slopes, separated by often dry valleys (Descoings, 1975; UNEP, 2014). There is no permanent drainage on the Batéké plateaus, and only a few marshes drain rainwater on an exceptional and temporary basis (Schwartz, 1988). However, the Nambouli, the nearest river, is located 18 km from Mpoh.

Populations and economic activities

The population of the northern sector of the Léfini reserve, particularly Mpoh, is mainly made up of individuals from the Tékés ethnic group and indigenous Atswa populations (Bouquet, 1969).

However, the opening up of overland communication routes has led to the arrival of other ethnic groups, including foreigners (UNDP, 2016).

The populations are mainly engaged in agriculture, gathering and illegal hunting. Human constraint linked to agricultural activities is exceptionally increasing cultivation areas, following the introduction of mechanized machinery in the means of production. However, poaching pressure is high, fuelled by the proliferation of weapons of all types and calibres. Weak surveillance and, above all, the proximity of the city of Brazzaville, with its buoyant market, fuel poaching (Ikamba-Nkulu and Tsoumou, 2009).

Materials

The biological material consists of woody individuals belonging to species with high economic potential, from the northern sector of the Léfini Reserve. The material is divided into three (3) categories, namely: (i) $d^{1-30} \geq 10$ cm, (ii) $1\text{cm} \leq d^{1-30} < 10$ cm and (iii) seedlings of height ≥ 30 cm. Identification of individuals in situ for common taxa and ex situ by consulting IEC herbariums and reference works (les arbres de la Sangha; Manuel d'identification illustré; les arbres de la Guinée Équatoriale) for those that could not be identified in the field.

The taxonomic ordination adopted is APG IV (2016) and the nomenclature is in agreement with Lebrun and Stork (1991-2015). The ecological parameters monitored are phytogeographic types (GT), diasporas types (DT) and leaf types (LT).

Phytogeographic types show the distribution of taxa across the globe. Chorological spectra of the flora provide information on the range of different species. The classification adopted in this study is that of White (1979, 1983), which highlights : species with a very wide distribution (Pantropical [Pant]; Afro-American [Afam]); African species with a wide distribution, other than regional species (continental Afrotropical [Aftr]; Afromalgache [Afma]) ; species from regional transition zones (Guineo-Congolese-

Zambezian [GC-Z]; Guineo-Congolese-Soudanian [GC-S]); species endemic to the Guineo-Congolian regional center of endemism (Guineo-Congolian[GC]; Lower Guineo-Congolian [BGC]).

The definition of the different types of diasporas adopted is that given by Dansereau and Lems (1957) and taken up by Lebrun (1960). The types of diaspores used in this study are: ballochores [(Ballo): diaspores expelled by the plant itself]; barochores [(Baro): heavy, non-fleshy diaspores]; pterochores [(Ptero): diaspores with aliform appendages]; sarcochores [(Sarco): totally or partially fleshy diaspores]; pogonochores [(Pogono): diaspores with feathery or silky appendages, egret hairs].

The leaf types adopted are those defined according to the classification of Raunkiaer (1934) and adopted by Makumbelo *et al.* (2023). These leaf types in the present study are: leptophylls [(Lepto) $< 0.2 \text{ cm}^2$]; mesophylls [(Meso) from 20 to 200 cm^2]; macrophylls [(Macro) from 2 to 20 dm^2]; megaphylls [(Mega) $> 20 \text{ dm}^2$].

Sampling device

Three square, georeferenced plots measuring 100 m \times 100 m (1 ha) were set up (Fig. 3). Each plot was subdivided into 16 plots of 25 m \times 25 m, i.e. 625 m^2 . In the center of each plot, a 5 m \times 5 m (25 m^2) plot was installed (Fig. 3).

Methods

Data collection was carried out in two phases: (i) floristic inventory and (ii) assessment of environmental factors. For dense tropical rainforests, several methods are used to study natural regeneration. In this study, two inventory techniques were coupled namely: full inventory for individuals of $d^{1.30} \geq 10 \text{ cm}$ and $1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$; as well as statistical inventory for seedlings of height $\geq 30 \text{ cm}$, a size below which according to Ramananjatovo (2013), seedling survival is low. Taking these three categories of individuals into account provides a better understanding of the notions of natural regeneration, as well as reliable and modelable results.

Floristic inventory

Floristic data were collected on all 3 plots. Within the 25 m \times 25 m plots, the inventory focused on individuals $d^{1.30} \geq 10 \text{ cm}$ and $1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$. Seedlings (individuals $\geq 30 \text{ cm}$ in height from the crown) were counted in the 5 m \times 5 m plots.

Environmental variable estimation

In the interest of understanding the factors that can influence the regeneration of commercial tree species, the factors taken into account were canopy openness, litter thickness and herbaceous cover. These factors were assessed in 5 m \times 5 m plots and coupled with the number of seedlings $\geq 30 \text{ cm}$ in height.

Canopy opening

Light is considered to be the dominant factor in regeneration dynamics. The percentage of canopy opening was assessed using the spherical densiometer from one point and in the four cardinal directions (Baudry *et al.*, 2013). The average of the four values gives an estimate of canopy density at the point in question. The scale used is as follows:

Class 1: opening $< 10\%$;

Class 2: opening between 10 and 20%;

Class 3: opening $\geq 20\%$.

Litter thickness

The thickness of the litter can influence regeneration as a result of low water retention and the fact that it prevents the seed from reaching the soil. An average of the measurements taken at the four corners of the plot gives its thickness. The scale used is as follows:

Class 1: bedding $< 5 \text{ cm}$;

Class 2: bedding between 5 and 10 cm ;

Class 3: bedding $\geq 10 \text{ cm}$;

Herbaceous cover

Herbaceous cover has been incorporated because herbaceous cover provides a degree of shade and competition for water, rapidly eliminating seedlings (Guérard *et al.*, 2001). For this assessment, the following scale has been adopted:

Class 1: no or low herbaceous cover (R $< 25\%$);

Class 2: medium herbaceous cover (R between 25 and 50%);

Class 3: high herbaceous cover (R > 50%).

Expression of results

Density (D), the number of individuals per unit area (Dallmeier; 1992)

$$D = \frac{\text{Total number of trees (or taxa) per plot.}}{\text{Surface area of plot in ha}}$$

Woody frequency (F) refers to the number of records in which the taxon is present in relation to the total number of records (Dallmeier, 1992);

$$F = \frac{\text{Number of plots where the taxon is present.}}{\text{Total number of plots.}}$$

The basal area (BA) is the sum of the cross-sectional areas of all stems measured at $d^{1.30}$ in the plots, per hectare. Basal area ($m^2 \cdot ha^{-1}$) is calculated using the following formula:

$$ST = \frac{\sum \pi D_i^2}{4}$$

Di: diameter of tree $d^{1.30}$

Species Importance Value Index (IVI)

The species importance value index (IVI) provides information on the number of individuals, distribution and level of spatial occupation of trunk sections projected on the ground (basal area) (Kimpouni, 2017).

These taxa were determined in relation to their density, basal area and relative dominance.

$$IVI = RF + RD + RDo$$

For seedlings ≥ 30 cm in height, the importance value index is derived from Douh's (2018) formula, which highlights the number of individuals and distribution.

$$IVI = RF + RD$$

Morisita dispersion index (Id)

The Morisita dispersion index (Id) must be equal to 1 for a random distribution; between 0.8 and 1 for a regular distribution and greater than 1 when the distribution is aggregative. This method verifies the calculation of the S^2 / m distribution index.

$$Id = n \left(\frac{\sum X^2 - N}{N(N-1)} \right)$$

With n : Total number of plots; N: Number of individuals per plot.

The values of the dispersion index (Id) were subjected to a chi-square test (χ^2) for $\alpha = 5\%$, to check whether they were significantly different from 1 (random dispersion).

$$\chi^2 (df = Q - 1) = (Q - 1)S^2 / \bar{X}$$

with Q the number of plots, S^2 and \bar{X} macron respectively the variance and mean of the number of trees per subplot.

Shannon's index of biological diversity, which corresponds to the diversity achieved by a community (Legendre and Legendre, 1998; Magurran, 2004);

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

with $p_i = n_i/n$; n_i = number of individuals of the species and/or family and n = total number of individuals.

Maximum diversity

The maximum diversity index (H' max) corresponds to the maximum diversity that a given community can reach at a well-defined time "t".

$$H'_{\max} = \ln S$$

Pielou's equitability

Pielou's Equitability (Eq) predicts the spatial distribution pattern of taxa and is equivalent to the ratio of H' to the theoretical maximum index in the stand, defined by the following formula :

$$Eq = H' / H'_{\max}$$

Taxon rarity index

Species with a rarefaction index of less than 80% are considered preferential, very frequent and abundant in the areas studied (Géhu and Géhu, 1980).

Taxa with a rarefaction index greater than 80% are considered rare and therefore highly threatened with extinction in the locality.

$$Ri = \left[1 - \frac{ni}{N}\right] \times 100$$

Ri designates the rarefaction index of a species i; ni the number of plots where the taxon is encountered and N the total number of plots inventoried.

Jaccard's similarity coefficient

This index is used to compare similarity and floristic diversity between plots. Its formula is as follows:

$$S (\%) = (C/A + B - C) \times 100$$

with A: the number of species in the first survey, B: the number of species in the second survey and C: the number of species common to both surveys.

Natural regeneration rate

Rothe's (1964) natural regeneration rate (TR), taken up by Ramananjatovo (2013), is used to judge a species' regeneration capacity.

$$TR = \frac{\text{Number of regenerating individuals}}{\text{Number of individuals other than regenerators}} \times 100$$

Regeneration is difficult if $TR < 100\%$.

Regeneration is good for $100 \leq TR < 1000\%$.

Regeneration is very good when $TR \geq 1000\%$.

Weighted and raw spectra

A spectrum is a description of the elementary syntaxon based on classifications other than floristic. The gross spectrum takes into account the number of species belonging to a given category or classification.

The raw spectrum is the ratio in % between the number of species in the category considered and the total number of species in the group. The weighted spectrum is based on presence and corresponds to the ratio between the number of individuals of species in a given category and the total number of individuals of species present in the group (de Foucault, 1996).

$$RS (\%) = \frac{\text{Number of species per category}}{\text{Total number of species}} \times 100$$

$$WS (\%) = \frac{\text{Number of individuals by category}}{\text{Total number of individuals}} \times 100$$

Frequency, biodiversity indexes, dispersion indexes and rarefaction indexes were presented by category of individuals rather than as a whole.

Results

Wood stand characteristics

Taxonomic data

The floristic inventory identified 1208 individuals belonging to 36 species and 20 families. In terms of diametric category, the individuals break down as follows: 118 seedlings of height ≥ 30 cm; 769 individuals of $1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$ and 321 individuals of $d^{1.30} \geq 10 \text{ cm}$ (Table 1). Fabaceae are the most represented with 7 species and are followed by Meliaceae (5 species). The least represented families, whose number of species varies between 1 and 4, include Anisophyllaceae, Burseraceae and Cannabaceae, each with one species (Table 2).

Table 1. Taxonomic data overview.

Surveys	Taxa			Number of individuals		
	Families	Species	Seedlings h ≥ 30 cm	$1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$	$d^{1.30} \geq 10 \text{ cm}$	Total
R1	15	29	31	268	84	383
R2	15	24	35	277	132	444
R3	17	26	52	224	105	381
Average \pm SE	15.67 \pm 0.67	26.33 \pm 1.45	39.33 \pm 6.44	256 \pm 16.37	107 \pm 13.89	402.67 \pm 20.67
A	20	36	118	769	321	1208

Legend: R1 = Survey 1, R2 = Survey 2, R3 = Survey 3, SE = Standard error, A = All study area.

Dominant taxa

The dominant species in the study area (based on at least 20 individuals each) number 14. *Petersianthus macrocarpus* (22.10%) is the characteristic species of

this ecosystem, ahead of *Entandrophragma* sp. (9.50%) and *Dialium pachyphyllum* (8.90%). These three taxa, each with more than 100 individuals, account for 40.50% of the total population. Taxa with

between 50 and 100 individuals represent 36.46% of the total, including *Staudtia kamerunensis* (7.70%), *Pycnanthus angolensis* (7.11%), *Treculia africana* (5.90%), *Blighia welwitschii* (5.30%) and *Piptadeniastrum africanum* (5.20%) *Anonidium manni* (4.80%). The least dominant species, with

fewer than 50 individuals, include *Grewia coriacea* (3.80%), *Albizia zygia* (2.40%), *Entandrophragma angolense* (2.06%), *Pentaclethra macrophylla* (1.90%) and *Antiaris toxicaria* (1.80%). Without being exhaustive, this group represents a total of 23.49% of the total inventory.

Table 2. Taxon bioecological and dendrometric data.

Taxa	GT	DT	LT	TR	Seedlings				1 cm ≤ d ^{1.30} < 10 cm				d ^{1.30} ≥ 10 cm				Total
					R1	R2	R3	A	R1	R2	R3	A	R1	R2	R3	A	
Anisophylleaceae					0	0	0	0	0	0	1	1	0	0	0	0	1
<i>Anisophyllea purpurascens</i> Hutch. & Dalziel	GC	Sarco	Meso	0.00	0	0	0	0	0	0	1	1	0	0	0	0	1
Annonaceae					0	0	0	0	12	15	7	34	8	10	7	25	59
<i>Anonidium manni</i> (Oliv.) Engl. & Diels.	GC	Sarco	Meso	132.00	0	0	0	0	11	15	7	33	8	10	7	25	58
<i>Xylopia staudtii</i> Engl. & Diels	Afr	Sarco	Micro	0.00	0	0	0	0	1	0	0	1	0	0	0	0	1
Burseraceae					0	0	0	0	4	2	0	6	1	2	0	3	9
<i>Canarium schweinfurthii</i> Engl.	GC	Sarco	Meso	200.00	0	0	0	0	4	2	0	6	1	2	0	3	9
Cannabaceae					0	0	0	0	2	2	4	8	5	5	1	11	19
<i>Celtis tessmannii</i> Rendle	Afr	Sarco	Micro	72.73	0	0	0	0	2	2	4	8	5	5	1	11	19
Chrysobalanaceae					0	0	9	9	0	0	0	0	1	1	1	3	12
<i>Parinari excelsa</i> Sabine	Afam	Sarco	Meso	300.00	0	0	9	9	0	0	0	0	1	1	1	3	12
Clusiaceae					0	0	0	0	1	8	0	9	0	0	0	0	9
<i>Garcinia kola</i> Heckel	GC	Sarco	Meso	0.00	0	0	0	0	1	8	0	9	0	0	0	0	9
Fabaceae					7	15	15	37	30	65	49	144	15	26	18	59	240
<i>Albizia zygia</i> (DC.) J.F. Macbr.	GC	Baro	Micro	625.00	4	7	3	14	1	8	2	11	0	2	2	4	29
<i>Amphimas ferrugineus</i> Pierre ex Pellegr.	GC	Ptero	Meso	0.00	0	0	0	0	2	0	0	2	0	0	0	0	2
<i>Dialium pachyphyllum</i> Harms	BGC	Sarco	Meso	535.29	3	8	5	16	17	38	20	75	3	10	4	17	108
<i>Millettia laurentii</i> De Wild.	BGC	Ballo	Micro	200.00	0	0	2	2	2	2	2	6	0	1	3	4	12
<i>Pentaclethra macrophylla</i> Benth.	GC	Ballo	Lepto	500.00	0	0	4	4	0	4	12	16	1	1	2	4	24
<i>Piptadeniastrum africanum</i> (Hook. f.) Brenan	GC	Ptero	Lepto	117.24	0	0	1	1	8	12	13	33	11	11	7	29	63
<i>Pterocarpus soyauxii</i> Taub.	BGC	Ptero	Meso	100.00	0	0	0	0	0	1	0	1	0	1	0	1	2
Irvingiaceae					0	0	0	0	0	0	0	0	1	0	0	1	1
<i>Irvingia gabonensis</i> (Aubry- LeComte ex O'Rorke) Baill.	GC	Sarco	Micro	0.00	0	0	0	0	0	0	0	0	1	0	0	1	1
Lauraceae					0	0	0	0	3	0	4	7	2	2	3	7	14
<i>Beilschmiedia insularum</i> Robyns & R. Wilczek	BGC	Sarco	Meso	100.00	0	0	0	0	3	0	4	7	2	2	3	7	14
Lecythidaceae					7	3	0	10	36	72	58	166	19	44	28	91	267
<i>Petersianthus macrocarpus</i> (P. Beauv.) Liben	GC	Ptero	Meso	193.41	7	3	0	10	36	72	58	166	19	44	28	91	267
Malvaceae					0	0	2	2	13	15	10	38	5	10	1	16	56
<i>Cola nitida</i> (Vent.) Schott & Endl.	GC-S	Sarco	Meso	150.00	0	0	0	0	3	0	0	3	2	0	0	2	5
<i>Grewia coriacea</i> Mast.	GC	Sarco	Meso	291.67	0	0	2	2	9	15	9	33	3	8	1	12	47
<i>Pterygota bequaertii</i> De Wild.	GC	Ptero	Meso	100.00	0	0	0	0	1	0	1	2	0	2	0	2	4
Meliaceae					4	9	12	25	71	23	22	116	6	3	3	12	153
<i>Entandrophragma angolense</i> (Welw.) C. DC.	GC	Ptero	Meso	525.00	0	0	0	0	21	0	0	21	4	0	0	4	25
<i>Entandrophragma candollei</i> Harms	GC	Ptero	Meso	0.00	0	0	0	0	0	0	0	0	0	0	1	1	1
<i>Entandrophragma</i>	GC	Ptero	Meso	0.00	0	0	0	0	4	0	0	4	0	0	0	0	4

<i>cylindricum</i> (Sprague) Sprague																	
<i>Entandrophragma</i> sp.	-	Ptero	Meso	1542.86	3	8	12	23	41	23	21	85	2	3	2	7	115
<i>Lepalaea cedrata</i> (A. Chev.) Pellegr.	GC	Sarco	Meso	0.00	1	1	0	2	5	0	1	6	0	0	0	0	8
Moraceae					3	3	1	7	21	27	18	66	11	4	7	22	95
<i>Antiaris toxicaria</i> Lesch.	GC	Sarco	Meso	2100.00	1	1	0	2	3	10	6	19	0	1	0	1	22
<i>Treculia africana</i> Decne.	Aftr	Sarco	Meso	242.86	2	2	1	5	17	17	12	46	11	3	7	21	72
<i>Trilepisium madagascariense</i> DC.	Afma	Sarco	Meso	0.00	0	0	0	0	1	0	0	1	0	0	0	0	1
Myristicaceae					9	4	7	20	53	34	34	121	6	16	17	39	180
<i>Pycnanthus angolensis</i> (Welw.) Warb.	GC	Sarco	Meso	230.77	3	1	1	5	19	12	24	55	3	9	14	26	86
<i>Staudtia kamerunensis</i> Warb.	BGC	Sarco	Meso	623.08	6	3	6	15	34	22	10	66	3	7	3	13	94
Olacaceae					0	0	0	0	0	0	3	3	0	0	0	0	3
<i>Ongokea gore</i> (Hua) Pierre	BGC	Sarco	Micro	0.00	0	0	0	0	0	0	3	3	0	0	0	0	3
Rubiaceae					0	0	0	0	0	0	0	0	0	0	1	1	1
<i>Morinda lucida</i> Benth.	GC	Sarco	Meso	0.00	0	0	0	0	0	0	0	0	0	0	1	1	1
Sapindaceae					1	1	4	6	15	12	7	34	1	8	16	25	65
<i>Blighia welwitschii</i> (Hiern) Radlk.	GC	Sarco	Meso	160.00	1	1	4	6	15	12	7	34	1	8	16	25	65
Sapotaceae					0	0	0	0	7	1	1	9	3	1	0	4	13
<i>Chrysophyllum africanum</i> A. DC.	GC	Sarco	Meso	225.00	0	0	0	0	7	1	1	9	3	1	0	4	13
Simaroubaceae					0	0	2	2	0	0	6	6	0	0	1	1	9
<i>Quassia africana</i> (Baill.) Baill.	GC	Sarco	Micro	800.00	0	0	2	2	0	0	6	6	0	0	1	1	9
Urticaceae					0	0	0	0	0	1	0	1	0	0	1	1	2
<i>Myrianthus arboreus</i> P. Beauv.	Aftr	Sarco	Macro	100.00	0	0	0	0	0	1	0	1	0	0	1	1	2
Total				276.32	31	35	52	118	268	277	224	769	84	132	105	321	1208

Structural parameters

Taxon density

The regenerative cohort of seedlings ≥ 30 cm in height is 39.33 ± 6.44 individuals per sampling unit (su). This class is supported by *Entandrophragma* sp. (7.67 individuals.su⁻¹), *Dialium pachyphyllum* (5.33 trees.su⁻¹), *Staudtia kamerunensis* (5 trees.su⁻¹), *Albiza zygia* (4.67 trees.su⁻¹), *Petersianthus macrocarpus* (3.33 trees.su⁻¹). $1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$: The density of individuals in this category is $256 \pm$

16.37 trees.ha⁻¹. Taxa supporting this density are *Petersianthus macrocarpus* (55 trees.ha⁻¹), *Entandrophragma* sp. (28.33 trees.ha⁻¹), *Dialium pachyphyllum* (25 trees.ha⁻¹), *Staudtia kamerunensis* (22 trees.ha⁻¹), *Pycnanthus angolensis* (18.33 trees.ha⁻¹), *Treculia africana* (15.33 trees.ha⁻¹), *Blighia welwitschii* (11.33 trees.ha⁻¹), *Grewia coriacea* (11 trees.ha⁻¹), *Piptadeniastrum africanum* (11 trees.ha⁻¹) and *Anonidium mannii* (11 trees.ha⁻¹); $d^{1.30} \geq 10 \text{ cm}$: Within this class, density is 107 ± 13.89 trees.ha⁻¹.

Table 3. Summary of biodiversity index scores.

Categories	Phytodiversity index	R1	R2	R3	Average \pm SE
Seedlings ($H \geq 30 \text{ cm}$)	Shannon (H')	2.11	1.99	2.28	2.12 \pm 0.08
	Highest diversity (H'_{\max})	2.30	2.30	2.56	2.39 \pm 0.09
	Pielou (J)	0.91	0.86	0.89	0.89 \pm 0.01
$1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$	Shannon (H')	2.73	2.48	2.57	2.59 \pm 0.07
	Highest diversity (H'_{\max})	3.26	3.00	3.09	3.11 \pm 0.08
	Pielou (J)	0.84	0.83	0.83	0.83 \pm 0.01
$d^{1.30} \geq 10 \text{ cm}$	Shannon (H')	2.53	2.42	2.42	2.45 \pm 0.04
	Highest diversity (H'_{\max})	2.94	3.05	3.00	2.99 \pm 0.03
	Pielou (J)	0.86	0.79	0.81	0.82 \pm 0.02

Legend: R1 = Survey 1, R2 = Survey 2, R3 = Survey 3, SE = Standard error.

The supporting taxa are *Petersianthus macrocarpus* (30.33 trees.ha⁻¹), *Piptadeniastrum africanum* (9.67 trees.ha⁻¹), *Pycnanthus angolensis* (8.67 trees.ha⁻¹), *Anonidium mannii* (8.33 trees.ha⁻¹), *Blighia welwitschii* (8.33 trees.ha⁻¹), *Treculia africana* (7 trees.ha⁻¹);

Taxon frequency

The species with the highest frequencies in the surveys range from 11.11 to 100%. The best-represented species in all categories are *Albizia zygia*, *Blighia welwitschii*, *Dialium pachyphyllum*,

Entandrophragma sp., *Petersianthus macrocarpus*, *Pycnanthus angolensis*, *Staudtia kamerunensis*, *Treculia africana*.

Seedlings ≥ 30 cm in height: Frequency varies from 33.33 to 100%. The ubiquitous species (frequency of 100%) are *Albizia zygia*, *Blighia welwitschii*, *Dialium pachyphyllum*, *Entandrophragma* sp., *Pycnanthus angolensis*, *Staudtia kamerunensis*, *Treculia africana*. Other taxa with a frequency of 66.67% include *Antiaris toxicaria*, *Leplaea cedrata* and *Petersianthus macrocarpus*.

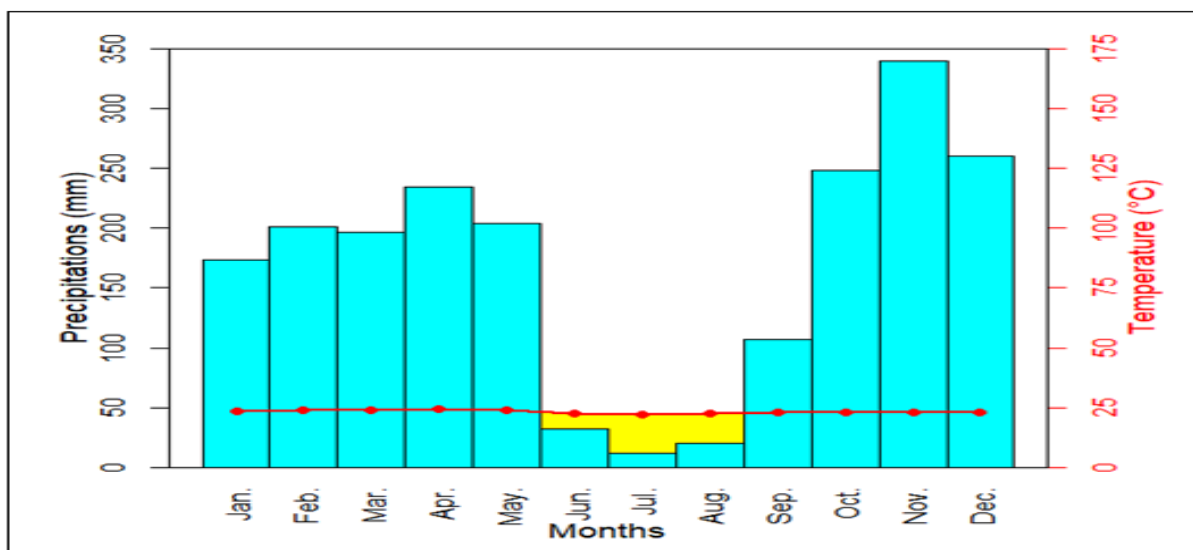


Fig. 2. Djambala umbrothermal diagram (ANAC 2010-2020 data).

1 cm $\leq d^{1-30} < 10$ cm: Taxon frequency ranges from 33.33 to 100%. Ubiquitous species include *Albizia zygia*, *Anonidium mannii*, *Antiaris toxicaria*, *Blighia welwitschii*, *Celtis tessmannii*, *Dialium pachyphyllum*, *Entandrophragma* sp., *Grewia coriacea*, *Milletia laurentii*, *Petersianthus macrocarpus*, *Pycnanthus angolensis*, *Treculia africana*. Taxa absent from one survey include *Beilschmiedia insularum*, *Canarium schweinfurthii*, *Garcinia kola*, *Leplaea cedrata*, *Pentaclethra macrophylla*, *Pterygota bequaertii*. These species have a frequency of 66.67%.

$d^{1-30} \geq 10$ cm: Species frequency varies from 33.33 to 100%. In addition to the ubiquitous taxa in the study area (*Albizia zygia*, *Blighia welwitschii*, *Entandrophragma* sp., *Dialium pachyphyllum*,

Pycnanthus angolensis, *Staudtia kamerunensis*, *Treculia africana*) are *Anonidium mannii*, *Beilschmiedia insularum*, *Celtis tessmannii*, *Grewia coriacea*, *Parinari excelsa*, *Pentaclethra macrophylla*, *Piptadeniastrum africanum*, *Canarium schweinfurthii*, *Chrysophyllum africanum*, *Entandrophragma candollei*, *Milletia laurentii*, *Morinda lucida*, *Myrianthus arboreus*, *Petersianthus macrocarpus*, *Quassia africana* are among the taxa distributed in two surveys, representing a frequency of 66.67%.

Basal area and basal area/density ratio

Average basal area is 13.12 ± 1.57 m².ha⁻¹. *Petersianthus macrocarpus* with 7.14 m².ha⁻¹ is the species with the best ground cover, all classes combined.

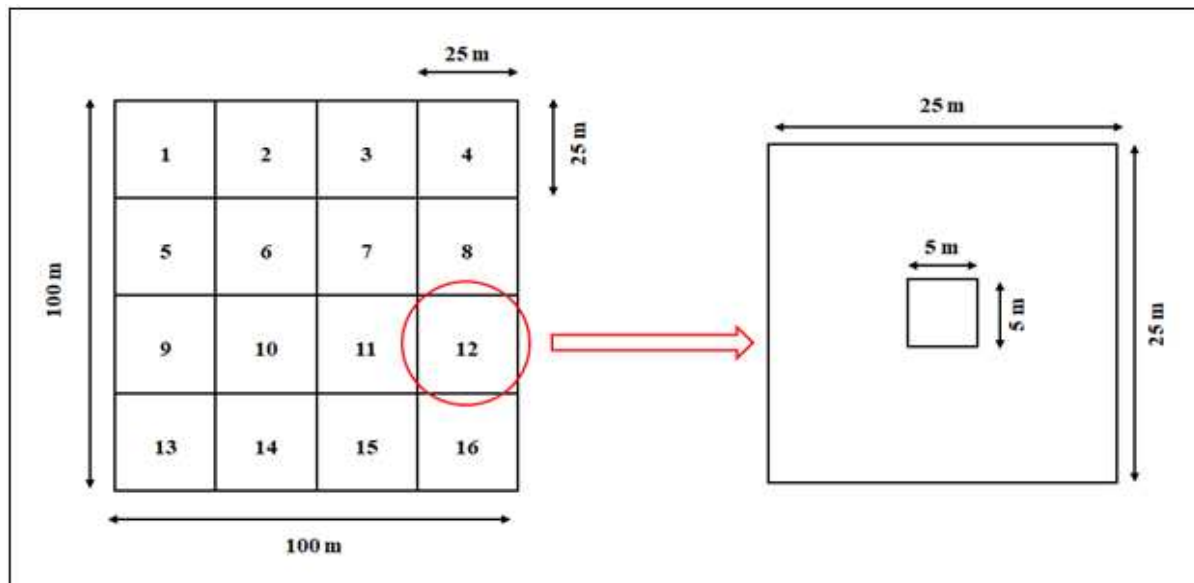


Fig. 3. Sampling device.

$1\text{ cm} \leq d^{1.30} < 10\text{ cm}$: the ground cover of taxa in this category is very low ($0.37\text{ m}^2.\text{ha}^{-1}$ on average). This coverage is supported mainly by *Petersianthus macrocarpus* ($0.10\text{ m}^2.\text{ha}^{-1}$), *Pycnanthus angolensis* ($0.03\text{ m}^2.\text{ha}^{-1}$), *Staudtia kamerunensis* ($0.03\text{ m}^2.\text{ha}^{-1}$), *Entandrophragma* sp. ($0.03\text{ m}^2.\text{ha}^{-1}$), *Dialium pachyphyllum* ($0.02\text{ m}^2.\text{ha}^{-1}$), *Anonidium mannii* ($0.02\text{ m}^2.\text{ha}^{-1}$). All other taxa have basal areas less than or equal to $0.019\text{ m}^2.\text{ha}^{-1}$; $d^{1.30} \geq 10\text{ cm}$: the

projected trunk sections of taxa in this category cover an area of $12.74\text{ m}^2.\text{ha}^{-1}$.

This basal area is largely supported by *Petersianthus macrocarpus* ($2.28\text{ m}^2.\text{ha}^{-1}$), *Piptadeniastrum africanum* ($1.95\text{ m}^2.\text{ha}^{-1}$), *Parinari excelsa* ($1.15\text{ m}^2.\text{ha}^{-1}$), *Celtis tessmannii* ($1.33\text{ m}^2.\text{ha}^{-1}$) and *Blighia welwitschii* ($1.04\text{ m}^2.\text{ha}^{-1}$). All other taxa have a basal area less than or equal to $0.76\text{ m}^2.\text{ha}^{-1}$.

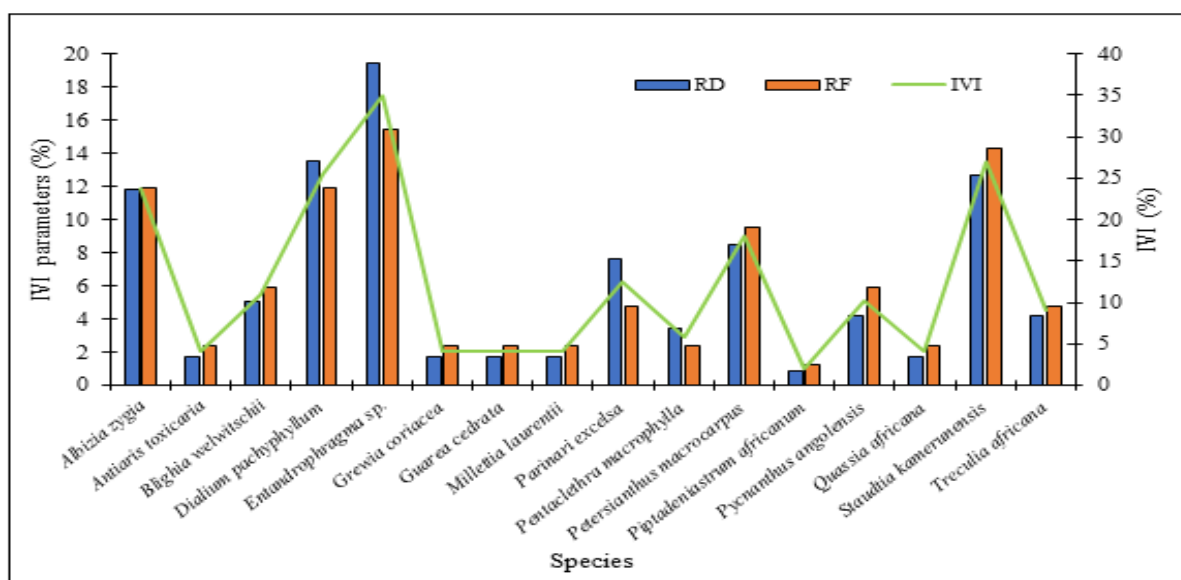


Fig. 4. IVI of seedlings $\geq 30\text{ cm}$ in height.

The ST/D ratio of 0.12 for trees of $d_{1.30} \geq 10\text{ cm}$ indicates the dominance of small-diameter species in the Mpo forest.

Morisita dispersion index

The Chi-square test of adequacy associated with the Morisita dispersion index highlights certain taxa

whose aggregative dispersion is significantly different from a random distribution. By category of individuals, these species are:

Seedlings ≥ 30 cm in height: *Albizia zygia*, *Dialium pachyphyllum*, *Entandrophragma* sp., *Parinari excelsa*, *Pentaclethra macrophylla*. $1 \text{ cm} \leq d^{1.30} < 10$ cm: *Anonidium mannii*, *Canarium schweinfurthii*, *Dialium pachyphyllum*, *Entandrophragma*

angolense, *Entandrophragma cylindricum*, *Entandrophragma* sp, *Garcinia kola*, *Grewia coriacea*, *Leplaea cedrata*, *Ongokea gore*, *Pentaclethra macrophylla*, *Petersianthus macrocarpus*, *Piptadeniastrum africanum*, *Staudtia kamerunensis*, *Treulia africana*. $d^{1.30} \geq 10$ cm: *Blighia welwitschii*, *Entandrophragma angolense*, *Grewia coriacea*, *Petersianthus macrocarpus*, *Piptadeniastrum africanum*, *Pterygota bequaertii*.

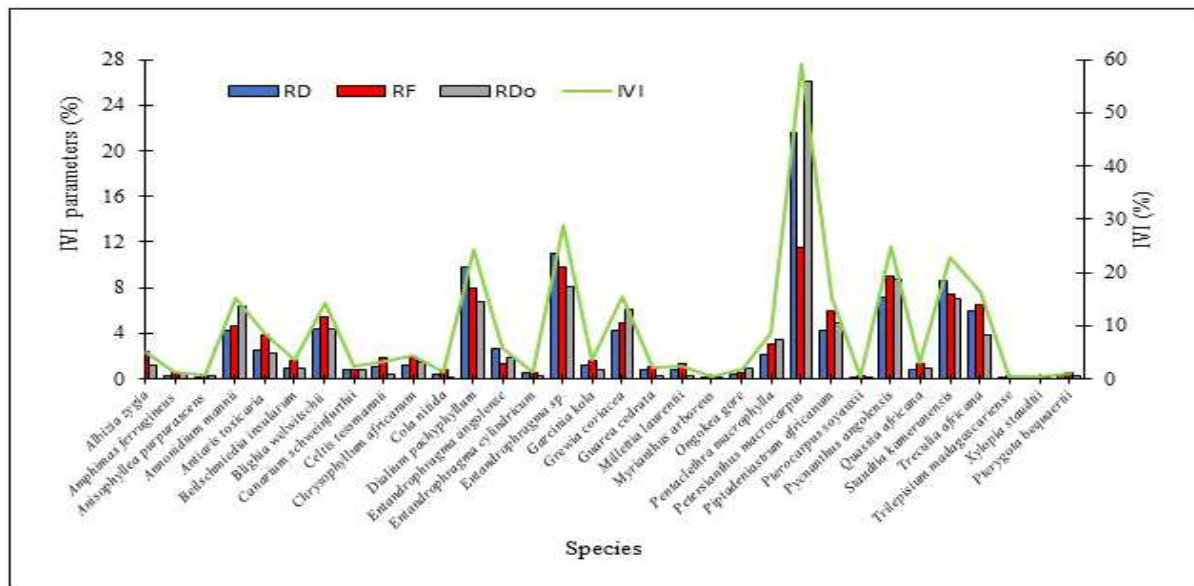


Fig. 5. IVI of individuals $1 \text{ cm} \leq d^{1.30} < 10$ cm.

Importance Value Index (IVI)

Seedlings ≥ 30 cm in height: The importance value index ranges from 4.08 to 34.97 (Fig. 4). The species with the highest importance value index in this category are *Entandrophragma* sp. (34.97%), *Staudtia kamerunensis* (27%), *Dialium pachyphyllum* (25.46%), *Albizia zygia* (23.77%), *Petersianthus macrocarpus* (18%), *Parinari excelsa* (12.39%). The least well represented species are *Piptadeniastrum africanum* (2.04%).

$1 \text{ cm} \leq d^{1.30} < 10$ cm: In this category, the importance value index ranges from 0.42 to 59.16 (Fig. 5). Species with a high importance value index are *Petersianthus macrocarpus* (59.16%), *Entandrophragma* sp. (28.92%), *Pycnanthus angolensis* (24.88%), *Dialium pachyphyllum* (24.39%), *Staudtia kamerunensis* (22.98%). The lowest values are associated with *Anisophyllea purpurascens* (0.72%) *Xylopia staudtii*

(0.48%), *Pterocarpus soyauxii* (0.57%), *Trilepisium madagascariense* (0.42%).

$d^{1.30} \geq 10$ cm: The importance value index in this category ranges from 0.80 to 63.91 (Fig. 6). The species with the highest importance value index in this category are *Petersianthus macrocarpus* (63.91%), *Piptadeniastrum africanum* (33.64%) and *Blighia welwitschii* (23.44%). The least represented species are *Myrianthus arboreus* (0.87%) and *Quassia africana* (0.80%).

Rarefaction index

The species rarefaction index reveals that anthropogenic activities are affecting floristic richness. The most common species are those that combine three essential factors for survival. These parameters are none other than a high capacity for diaspore production, an intrinsic power of

exceptionally efficient dissemination and adequate interspecific competitiveness. In this game, anemochorous taxa are generally the favorites. Seedlings ≥ 30 cm in height: 3/4 of taxa are rare,

against 1/4 common. Abundant species are *Albizia zygia* (79.17%), *Dialium pachyphyllum* (79.17%), *Entandrophragma* sp. (72.92%), *Staudtia kamerunensis* (75.00%).

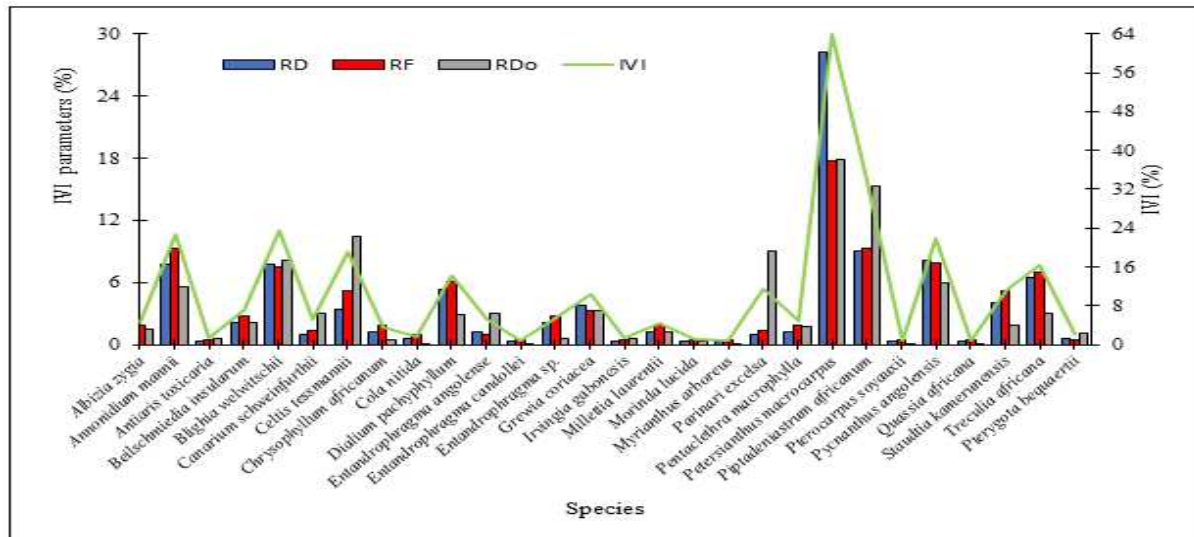


Fig. 6. IVI of individuals with $d^{1-30} \geq 10$ cm.

$1 \text{ cm} \leq d^{1-30} < 10$ cm: the species rarity index shatters this class, in the proportions of 2/3 rare and 1/3 common. Abundant species are *Anonidium mannii* (64.58%), *Antiaris toxicaria* (70.83%), *Blighia welwitschii* (58.33%), *Entandrophragma* sp. (25%), *Grewia coriacea* (62.50%), *Pentaclethra macrophylla* (77%), *Petersianthus macrocarpus* (12.50%), *Piptadeniastrum africanum* (54.17%), *Pycnanthus angolensis* (31.25%), *Staudtia kamerunensis* (43.75%), *Treculia africana* (50.50%).

$d^{1-30} \geq 10$ cm: the rarity index divides the taxa in this class, with 68% rare and 32% common. Abundant species are *Anonidium mannii* (58.33%), *Blighia welwitschii* (66.67%), *Celtis tessmannii* (77.88%), *Dialium pachyphyllum* (72.92%), *Pentaclethra macrophylla* (20.93%), *Piptadeniastrum africanum* (58.33%), *Pycnanthus angolensis* (64.58%), *Staudtia kamerunensis* (77.08%), *Treculia africana* (68.75%).

Biodiversity parameters

Shannon indices and maximum diversity

Seedlings ≥ 30 cm in height: The Shannon index for the study area is 2.12 ± 0.08 . However, the maximum diversity index is 2.39 ± 0.09 . These data show that the level of diversity in this cohort is very high (Table

3).

$1 \text{ cm} \leq d^{1-30} < 10$ cm: The Shannon index for the study area is 2.59 ± 0.07 and the maximum diversity index is 3.11 ± 0.08 . These parameters indicate a high level of diversity in this cohort. These parameters indicate a high level of specific diversity in this category (Table 3).

$d^{1-30} \geq 10$ cm: The Shannon index is 2.45 ± 0.04 in the study area. The maximum diversity index is 2.99 ± 0.03 . This indicates a high degree of species diversity (Table 3).

Pielou index

The equitability index (Pielou) in the three classes varies on average from 0.82 ± 0.02 to 0.89 ± 0.01 (Table 3). Values of this index tending towards 1, in all three communities, suggest a homogeneous distribution of taxa.

Floristic similarity between communities

Floristic similarity of different categories

Floristic comparison of the three communities, according to Jaccard's similarity coefficient, reveals

dissimilarity (45.45%) between the flora the regenerative cohort of seedlings of height ≥ 30 cm and that of $1 \text{ cm} \leq d^{1.30} < 10$ cm. As for the others, a medium and progressive degree of similarity is noted between the flora of (i) the regenerative cohort of seedlings of height ≥ 30 cm and $d^{1.30} \geq 10$ cm

(51.72%); and (ii) $1 \text{ cm} \leq d^{1.30} < 10$ cm and $d^{1.30} \geq 10$ cm (66.67%). These data indicate a slightly dissimilar floristic composition between communities. In addition to the ecological parameters of the environment, intra- and interspecific competition could explain this result.

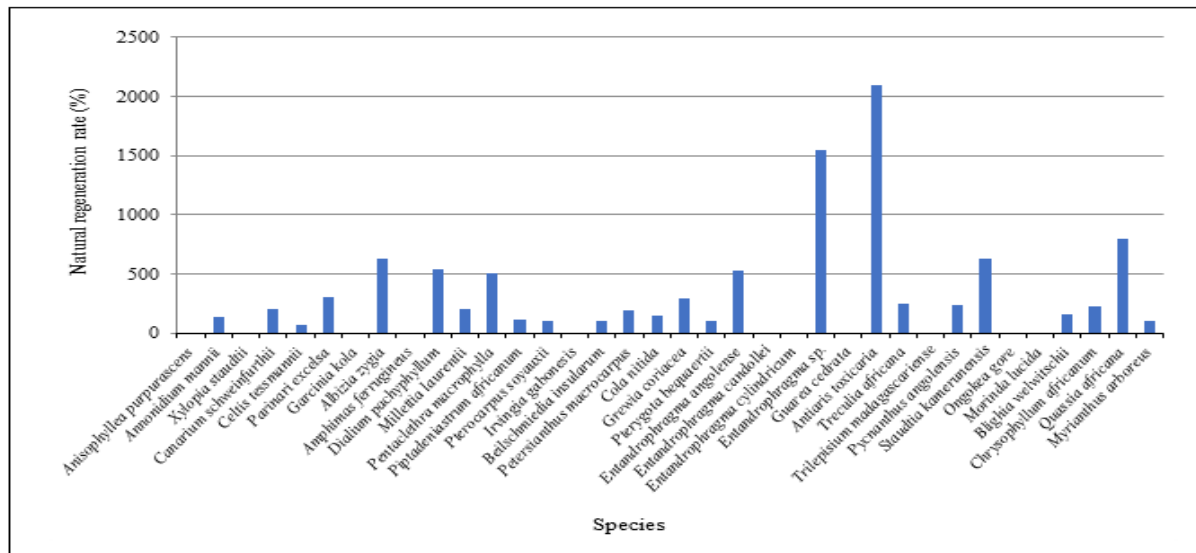


Fig. 7. Rate of natural regeneration in the area.

The species common to the different surveys number 14, namely: *Albizia zygia*, *Antiaris toxicaria*, *Blighia welwitschii*, *Dialium pachyphyllum*, *Grewia coriacea*, *Millettia laurentii*, *Pentaclethra macrophylla*, *Piptadeniastrum africanum*, *Petersianthus macrocarpus*, *Pycnanthus angolensis*, *Entandrophragma* sp., *Staudtia kamerunensis*, *Treculia africana*, *Quassia africana*.

Natural regeneration potential

The majority of species show good natural regeneration ($100 \leq \text{TR} < 1000$ %), such as *Quassia africana*, *Albizia zygia*, *Staudtia kamerunensis*, *Entandrophragma angolense*, *Dialium pachyphyllum*, *Pentaclethra macrophylla*, *Parinari excelsa*. Species with poor natural regeneration ($\text{TR} < 100\%$) include *Anisophyllea purpurascens*, *Celtis tessmannii*, *Irvingia gabonensis*, *Entandrophragma candollei*, *Entandrophragma cylindricum*, *Laplaea cedrata*, *Trilepisium madagascariense*, *Ongokea gore*, *Morinda lucida*. Among the species with good and poor natural regeneration, *Entandrophragma* sp. is the only one with a very good rate (Fig. 7). At the

current level of data on natural regeneration, taxa with $\text{TR} < 100\%$ would require support in view of the associated socio-economic and biodiversity conservation value.

Ecological parameters

Phytogeographical spectra

Phytogeographic spectra reveal that more than 3/4 of the species in each stratum form the base element. Despite the fact that the site is located in the Lower Guinean subcenter of endemism, Guineo-Congolian taxa dominate the flora (Fig. 8).

The contribution of other phytogeographical elements is the tangible sign that would justify a low degree of floristic intrusion in the zone.

Spectrum of diasporas

Diaspore spectra reveal that around 2/3 of taxa are sarcochorous at all inventory levels (Fig. 9). This dominance of sarcochores indicates that zoochory is the main mode of dissemination in this ecosystem, hence its high level of maturity.

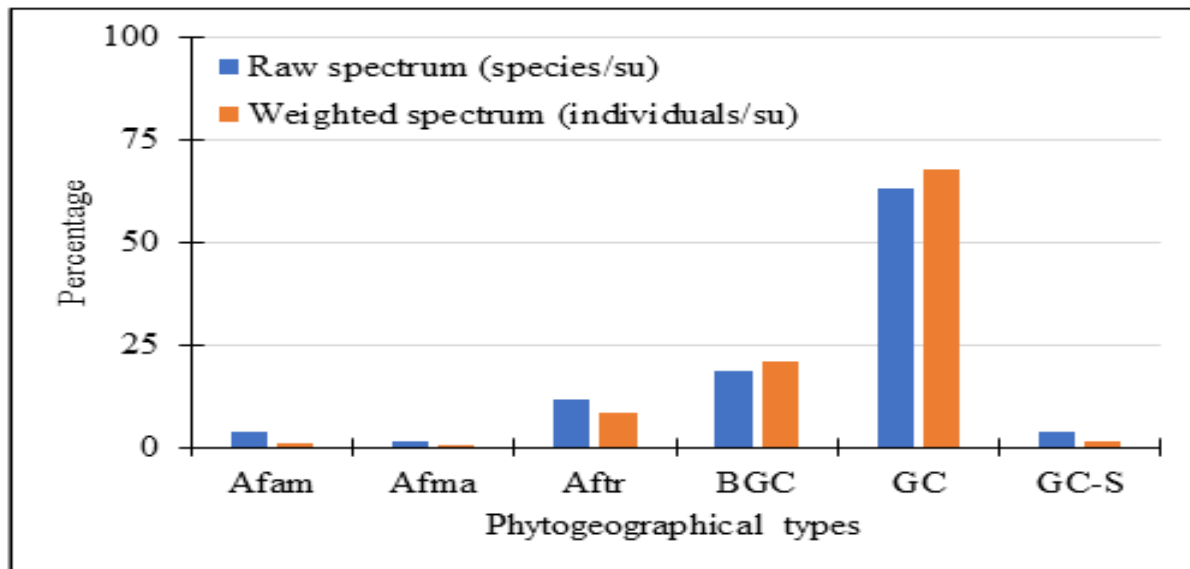


Fig. 8. Phytogeographical spectra.

Foliar spectra

Leaf spectra reveal that over 2/3 of taxa, across all strata, have mesophilic leaves (Fig. 10). This preponderance of mesophilic leaves suggests low competition for light.

Influence of environmental factors

Effect of litter thickness

Litter thickness is a factor influencing germination and seedling development. In the northern sector of the Léfini reserve, the number of seedlings increases in proportion to litter thickness, before decreasing once the litter becomes too thick (Fig. 11). The best results are obtained when litter thickness oscillates in the 0-10 cm range. Beyond this thickness, the number of seedlings is greatly reduced.

Herbaceous cover

Herbaceous cover has an impact on seed germination and development under forest cover. The greater the cover, the fewer seedlings per unit area. Under the forest in the northern sector of the Léfini reserve, the best result is observed with a cover rate of 0 to 24.9%. Beyond this range, the number of seedlings inventoried is almost 3 to 4 times lower (Fig. 11).

Canopy opening

Canopy opening has a positive effect on seedling behavior. As seedling development is strongly

associated with brightness, the best results are obtained with the most significant openings (Fig. 11). The canopy's openness favours the flow of light necessary and sufficient for the development of herbaceous plants. The corollary of this openness is intraspecific competition, often in favour of herbaceous plants.

Discussion

Phytodiversity analysis

Analysis of the Mpoh forest undergrowth, compared with known tropical forest data, reveals a pauciflorous and paucispecific character of first-growth taxa (Trochain, 1980; Puig, 2001; Pascal, 2003). This double poverty can be explained by the mesophilic and trophophilic traits that condition their development (Makany, 1976; Odum, 1976; Puig, 2001; Kimpouni *et al.*, 2017). In addition to the markers of this ecosystem, the effects of anthropogenic disturbance accentuate this low specific and floristic level (Fournier and Sasson, 1983; Puig, 1995; Servant and Servant-Vildary, 2000). Despite the low floristic diversity observed in the dominated stratum of the Mpoh forest, almost all the families typical of Congo Basin forests recognized by Kimpouni *et al.* (2014) have been recorded (Annonaceae, Clusiaceae, Fabaceae, Malvaceae, Meliaceae, Myristicaceae, Rubiaceae and Sapotaceae). The presence of these families in the undergrowth

and the dominance of Fabaceae would confirm that this woody formation belongs to the rainforests of the Congo Basin (Kouka, 2006; Kimpouni, 2009; Kimpouni, 2017; Nangalire *et al.*, 2017; Gueulou *et*

al., 2018; Kimpouni *et al.*, 2020; Miabangana *et al.*, 2020). This forest formation is just one of the variants of the dense forests of Central Africa, whose determinism is pedoclimatic.

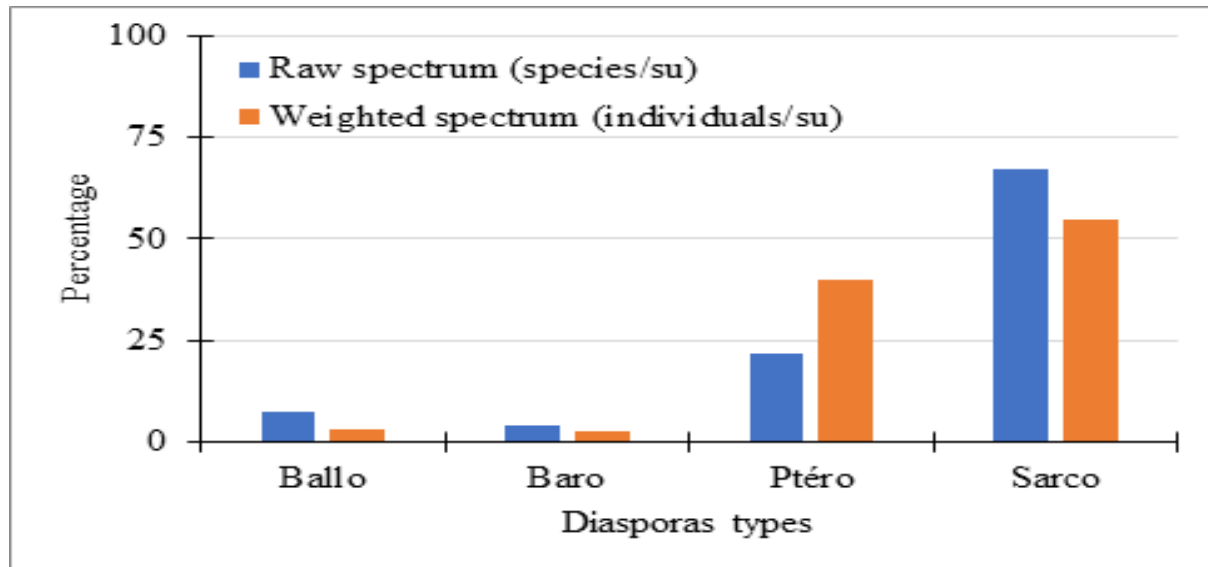


Fig. 9. Diaspora spectra.

The floristic composition of the Mpoh forest, analyzed from a phytosociological angle, reveals the existence of numerous taxa from the Canarion Schweinfurthii alliance (*Blighia welwitschii*, *Dialium pachyphyllum*, *Entandrophragma angolens* and *Piptadeniastrum africanum*), as shown by Cusset (1989). This floristic affinity between the Mpoh forest facies and the Mayombe forest would be proof of the common origin of the two ecosystems.

Comparative analysis of the floristic composition of the Mpoh understory shows strong similarities with the mesophilic and tropophilic woody formations of the Cataractes and Niari (Kimpouni, 2008, 2009; Kimpouni *et al.*, 2012, 2019; Miabangana *et al.*, 2020). However, dissimilarities have been noted between the mesophilic and tropophilic forest patches of Léfini and those of Patte d'Oie in Brazzaville (Kimpouni *et al.*, 2014, 2013). These aforementioned floristic similarities and dissimilarities are based on the pedoclimatic determinism that governs the development of these woody formations, notwithstanding variations in the degree of anthropization (Koubouana, 2010; Koubouana *et al.*, 2019). Abundance-dominance analysis plebiscites

Petersianthus macrocarpus and *Entandrophragma* sp. as markers of the Mpoh undergrowth. Indeed, these taxa are of particular interest to the local population for their seasonal supply of caterpillars (Lisingo *et al.*, 2010; Ngute *et al.*, 2019; Looli *et al.*, 2021; Mabossy-Mobouna *et al.*, 2022). In addition to the influence of pedoclimatic factors, the rarefaction of certain taxa in the Mpoh undergrowth is thought to be linked to the selective harvesting of gaulettes by surrounding populations, trampling by large mammals and juvenile mortality of individuals (Janzen, 1970; Baraloto, 2003; Fournier *et al.*, 2008; Agbangla *et al.*, 2015; Kimpouni *et al.*, 2013, 2020).

Undergrowth structure

The structural cohort of the Mpoh forest understory is characterized by the preponderance of heliophilous and semi-heliophilous individuals. This taxon behaviour is the result of the selective and recurrent harvesting of large-diameter individuals, necessary for the supply of timber, handicrafts and habitat. Sawmilling, which is of interest to some of the largest taxa, is the main source of timber for the surrounding urban cities, notably Brazzaville (Lescuyer *et al.*, 2011).

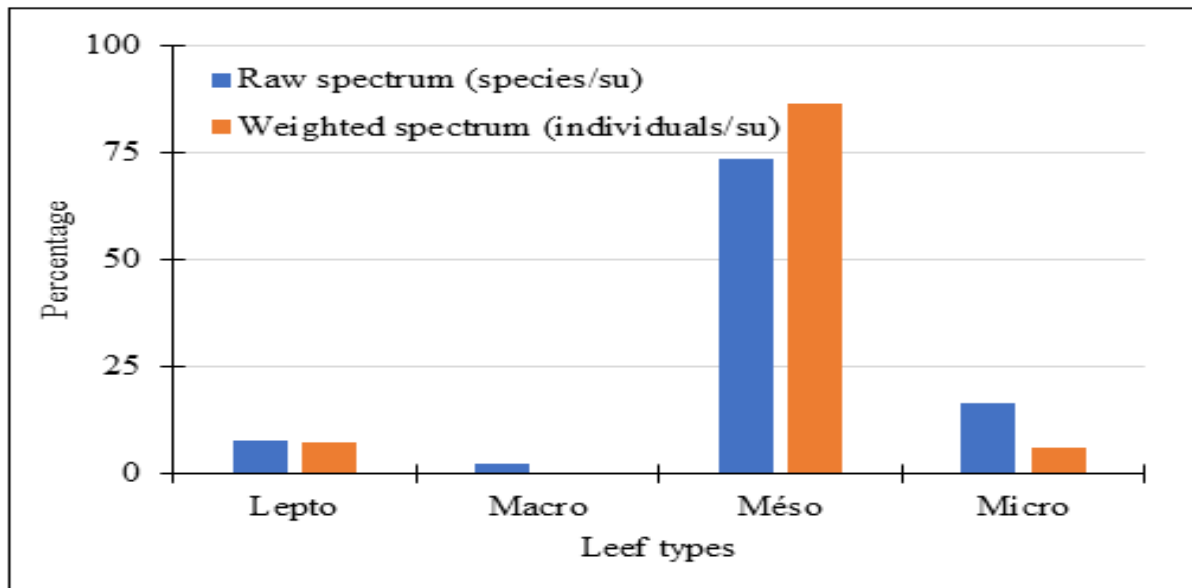


Fig. 10. Foliar spectra.

These types of disturbance, coupled with the natural functioning mechanisms of tropical forest ecosystems such as windthrow, would result in the coexistence of several taxa in the forest facies of the study area (Mangambu *et al.*, 2013). Analysis of the distribution of juvenile individuals reveals an evolution from aggregated to random structure, from the seedling category (height ≥ 30 cm) to $d^{1.30} \geq 10$ cm. This behavior would be governed by the non-extensive nature of the living space and the strong competition within this category of individuals, which induce a very high degree of natural mortality of seedlings, during recruitment to the adult stage (Baraloto, 2003; Bagchi *et al.*, 2011; Kimpouni *et al.*, 2020). Ground projection of trunk cross-section shows a concomitant increase in basal area, during the transition from the category $1 \text{ cm} \leq d^{1.30} < 10 \text{ cm}$ to $d^{1.30} \geq 10 \text{ cm}$. This increase is proportionally sustained and correlated with the predominance of *Petersianthus macrocarpus*. The predominance of small-diameter individuals in these forest facies, as highlighted by the ST/D ratio, is thought to be a consequence of anthropogenic activity. Indeed, the harvesting of gaulettes, primary materials for handicrafts and housing, affects the regularity of recruitment within diameter classes (Rabeniala *et al.*, 2013). Thus, a very low rate of 1 cm individuals $\leq d^{1.30} < 10 \text{ cm}$ reach the $d^{1.30} \geq 10 \text{ cm}$ class where large-diameter trees feed the sawmill.

Analysis of bioecological parameters

Phytogeographical data on the juvenile flora of Mpho provide evidence that this forest facies in the northern Léfini sector belongs to the Guineo-Congolian endemism center. This observation is supported by the dominance of the Guinean-Congolese base element and the existence of more than 75% of the marker families of the regional Guinean-Congolese endemism center (White, 1983). This phytogeographical analysis highlights the floristic purity of the Mpho forest (White, 1983). Although the Mpho forest is totally anchored in the Sangha-River corridor, the intrusion of taxa from neighbouring regions has hardly affected its floristic composition. Despite any observed anthropogenic disturbance, the high rate of endemism is underpinned by the very low degree of natural alteration of the understory flora. Data on leaf types in the Mpho forest understory reveal the dominance of mesophyll. This floristic character would seem to reflect the low level of competition for light in this forest. Indeed, because of its photosynthetic function, leaf type is one of the criteria for selecting individuals in forest ecosystems (Senterre, 2005; Gaudio, 2010; Kimpouni, 2017). This phenomenon is amplified by the non-joining feature of crowns at all strata of almost all forest facies in the northern sector of the Léfini reserve. Finally, coupled data on leaf type and spread of understory taxa would underpin a high degree of

maturity reached by this Mpoh forest ecosystem (Puig, 2001; Ngueguim *et al.*, 2016; Adiko *et al.*, 2020).

Analysis of diaspora dispersal and natural regeneration

Analysis of the diaspora types of understory taxa in the Mpoh forest formation reveals a dominance of

sarcochores. Thus, zoochory, and in particular endozoochory, is the most responsive mode of diaspora dissemination in phytocoenosis (De Foresta *et al.*, 1984; Miabangana and Lubini, 2015; Kimpouni *et al.*, 2012, 2014, 2020). The predominance of sarcochory within this Lefini forest facies would reflect the stage of maturity reached by the forest facies.

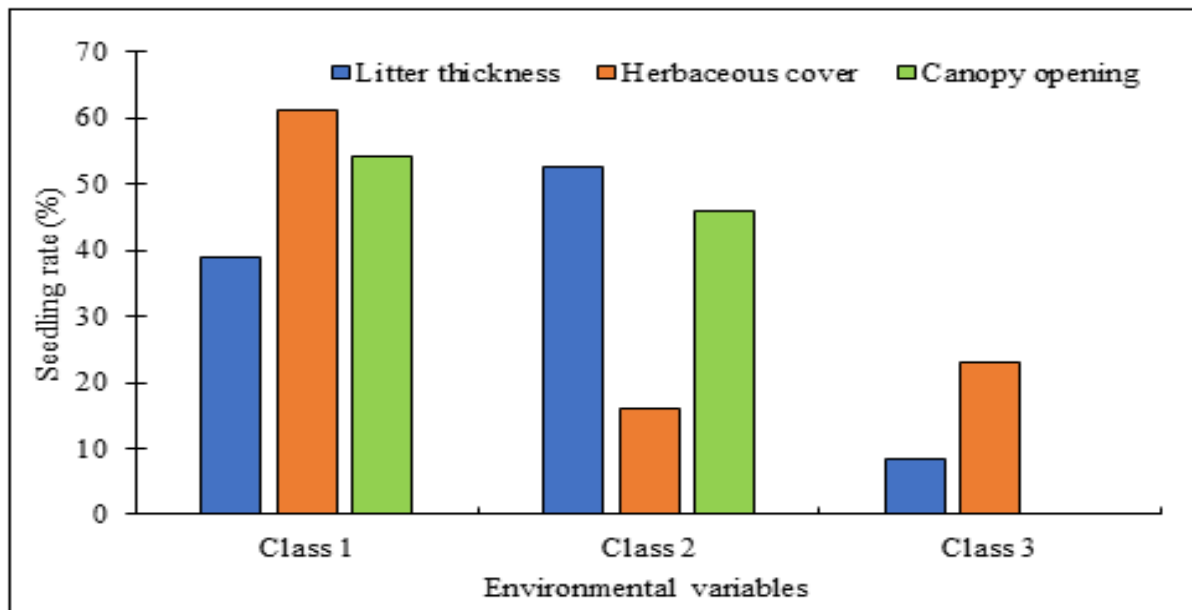


Fig. 11. Evolution of seedlings as a function of environmental variables.

The regenerative potential of the forest is thought to be the work of mammalian dissemination, influenced by environmental factors such as canopy openness, litter thickness and herbaceous cover (Gallet and Pellissier, 2002; Ngueguim *et al.*, 2010; Katusi Lomalisa *et al.*, 2022). The very high rate of sarcochores showing good regeneration highlights the importance of Mammals in maintaining this ecosystem (Holbrook and Smith, 2000; Evrard *et al.*, 2017). As for the variations in interspecific regeneration rates noted, within the Mpoh forest, the basis would be a consequence of anthropic action, notably the removal of diaspores (Peters, 1997; Tchataat and Ndoye, 2006; Kouakou *et al.*, 2018).

Conclusion

The forest formations of the northern Léfini sector are mesophilic and tropophilic ecosystems. Like the Cataractes and Niari Valley formations of the same

type, they are united by a pauciflorous and paucispecific trait, despite the proven continuity of the Mayombian forest and therefore the Central African ombrophilous forest. Floristic data show that *Petersianthus macrocarpus* is characteristic of this flora and *Entandrophragma* sp. is the dominant taxon in the undergrowth. Although located in the Sangha-River corridor, phytogeographical analysis shows very little intrusion of elements from outside the regional center of Guineo-Congolian endemism.

Petersianthus macrocarpus is the taxon most favored by the population. As a caterpillar provider, *Petersianthus macrocarpus* is a sacralized species that is not exploited. Phytoecological analysis reveals that the Mpoh forest in the northern sector of the Léfini reserve, in its current composition, has reached a fairly high degree of maturity and is continuing its development towards the climax stage with *Parinari*

excelsa. Despite the very marked anthropic effect, the natural regeneration of the first-growth taxa with high economic potential shows good regeneration overall. This observation should not obscure the difficult regeneration of certain taxa which, at the present stage, require assisted regeneration.

However, natural regeneration is strongly influenced by environmental variables such as litter thickness, herbaceous cover and canopy openness.

Conflict of interest

The authors declare that they have no competing interests.

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