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Ecological importance of trees and structure of forest types in the Likouala swamp forest, Republic of Congo

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Abstract

Current knowledge, although significant, does not yet provide a full understanding of the functioning of swamp forests in Central Africa. The aim of this study was to estimate the species importance value index (IVI) and characterise the stand structure of three forest types in the Likouala swamp forest in the north of the Republic of Congo. The forest inventory was carried out in flooded forest (FF), periodically flooded forest (PFF) and terra firme forest (TFF), focusing only on trees with a diameter of 10 cm or more. In each forest type, species of very high ecological importance value made up more than 56% of the species recorded, and their numbers increased as we moved from TFF to FF, with a marked predominance of sciaphyte species. This dominance was corroborated by the inverted J-shaped distribution curves observed in the three types of forest, indicating good natural regeneration. Furthermore, the mean values for stem density per hectare decrease from FF (445 ± 8 stems/ha) to TFF (351 ± 13 stems/ha), while those for basal area and height tend to increase in the same order, from 30.00 ± 2.1 m²/ha to 35.46 ± 3.2 m²/ha and from 20.26 ± 4.20 m to 26.10 ± 5.82 m respectively. In short, the low representation of pioneer species suggests a gradual evolution of each type of Likouala swamp forest towards a mature stage, characterised by a physiognomy dominated by sciaphyte species.

Keywords: Republic of Congo; Likouala swamp forest; Forest types; Importance value index; Stand structure

1. Introduction

In the Republic of Congo, swamp forests account for 44% of the total forest area [1]. They are typical of the forests of the central basin of the Congo Basin, which develop and persist on soil that is flooded for part of the year, and then present three forest types. Congolese swamp forests, which are generally flooded, are found in large depressions and poorly drained lowlands [2]. Today, studies monitoring deforestation and forest degradation highlight a sharp reduction in their forest cover [1]. In fact, we are witnessing strong deforestation and forest degradation of facies characteristic of Congolese swamp forests, linked mainly to the installation of palm groves, logging and population growth in the north of the country [3]. To avoid high atmospheric CO_2 emissions linked to the anthropisation of swamp forests, which are home to the largest forest peatland in the world [4], sustainable management measures are required.

Ecological research carried out in recent years has revealed that a better understanding of the stand structure, floristic diversity and carbon storage capacity of tropical ecosystems, particularly in developing countries, is crucial to their sustainable management. Ecological knowledge of horizontal structure (density and basal area), diametric structure and vertical structure (tree height distribution) makes it possible to monitor the dynamics of a forest ecosystem in terms of plant succession [5–7]. For example, the decrease in density and the increase in basal area indicate a gradual evolution of an *Aucoumea klaineana* P. forest towards a mature stage, the establishment of a rainforest [7]. Moreover, Pan et al. [8] noted a strong correlation between tree height and forest diversity. However, it should be noted that only structural

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parameters best explain the spatiotemporal variability of carbon stocks in tropical forests [9–13]. For this reason, monitoring the variation of certain structural parameters, such as basal area, stem density, diametric distribution and tree size, is very crucial for assessing the impact of human disturbance on forest dynamics at local and regional scales [14,15].

However, current knowledge, important as it is, does not yet allow us to understand how tropical floodplain forests, which are among the most complex terrestrial ecosystems in the world, function [16]. Very little ecological research has been carried out on these particular ecosystems. Hence the need to carry out ecological studies on the mapping, structure and floristic diversity, and then on the carbon fixation and storage capacities of the facies characteristic of the swamp forests of Central Africa. It is in this context that the present study is being carried out, with the aim of to estimate the species importance value index (IVI) and characterise the stand structure of three forest types in the Likouala swamp forest in the north of the Republic of Congo.

2. Materials and Methods

2.1. Study area

Our study area has a surface area of 30,000 km² and belongs to the north-eastern Likouala region of the Congolese territory. It is bounded to the north by the Dongou (Bondzalé) district, to the east by the Oubangui river, to the west by the Likouala grassland river and to the south by the Bouanela district [13]. The average annual temperature and rainfall are 25.6 °C and 1556.5 mm respectively [17]. The soil are peaty or gleysols [18] and the relief is generally flat [19]. Vegetation in Likouala is mainly represented by swamp forests that are generally flooded. Three forest facies or forest types can be distinguished as characteristic of these swamp forests [20,21]: flooded forest, periodically flooded forest and terra firme forest.

2.2. Forest inventory

The experimental plots were set up along three transects 6 to 9 km long, covering: flooded forest (FF), periodically flooded forest (PFF) and terra firme forest (TFF). Twenty-seven 1600 m² plots, nine per transect and three per facies, were set up in Bondzalé, Itanga and Ekolongouma (Table 1). Two plots of 1 ha each and two plots of 0.6 ha each were set up respectively in the TFF and the FF of the Ekolongouma transect. Each of the thirty-one plots was subdivided into 400 m² plots [22], giving a total of 188 sampling units. The total sampling area used corresponds to 7.06 ha.

Table 1 Distribution of study plots by site and forest types

Sites	Length of transects	Plot size	Number of plots			Total
			FF	PFF	TFF	
Bondzalé	6 km	40mx40m	3	3	3	9
Itanga	6 km	40mx40m	3	3	3	9
Ekolongouma	9 km	40mx40m	3	3	3	9
		100mx100m	/	/	2	2
		60mx100m	2	/	/	2
Total			11	9	11	31

FF: flooded forest; PFF: periodically flooded forest; TFF: terra firme forest

Only trees with a diameter of at least 10 cm at breast height (dbh) were measured in the study plots of each plot. The local and scientific names of the trees were determined. A herbarium was set up for species not identified in the field, for botanical identification at the national herbarium in Brazzaville.

2.3. Data processing and analysis

2.3.1. Ecological importance of tree species

The ecological importance value index (IVI) was calculated for each species *i* in the swamp forest studied. It corresponds to the sum of the indices of relative frequency, relative density and relative dominance of the species [23]:

$$IVI = Relative\ frequency + Relative\ density + Relative\ dominance \qquad .... \quad (1)$$

The relative frequency of species *i* is the ratio between its frequency (number of records in which it is present) and the sum of the frequencies of all the species, multiplied by 100. Relative density is the ratio between the number of individuals of the species and the total number of individuals, multiplied by 100. Relative dominance is the ratio between the total basal area of a species and the sum of the basal areas of all the species, multiplied by 100.

2.3.2. Horizontal structure

It was assessed by calculating density and basal area:

$$Density = \frac{Number\ of\ individuals\ (ni)}{Per\ hectare\ (1ha)} \qquad ...... \qquad (2)$$

$$Basal\ area = \frac{\pi}{4} \sum_{i=1}^{n} di^2 \qquad .... \qquad (3)$$

With d_i = diameter of individual i and n = number of individuals

2.3.3. Vertical structure

It was assessed by the distribution of tree heights by dhp class of amplitude 10 cm [24], at the level of flooded forest, periodically flooded forest and terra firme forest. Only the height of 20 trees for diameter classes I]10-20], II]20-30], III]30-40], IV]40-50] and class V≥50 cm was taken.

2.3.4. Diametric structure

Trees of dbh ≥ 10 cm were divided into diameter classes of 10 cm amplitude and the number of trees per diameter class were determined [25].

3. Results

3.1. Ecological importance of tree species

Of the 68, 50 and 51 tree species recorded, the number of those with a high ecological importance value was 7, 9 and 10 respectively for the terra firme forest (TFF), the flooded forest (FF), the periodically flooded forest (PFF). *Carapa procera* DC.*, Symphonia globulifera* L.f.*, Uapaca mole* Pax*, Grossera macrantha* Pax*, Drypetes occidentalis* (Müll. Arg.) Hutch.*, Entandrophragma palustre* Staner*, Xylopia rubescens* Oliv., *Manilkara fouilloyana* Aubrév. & Pellegr. and *Eriocoelum microspermum* Gilg ex Radlk. were, in descending order, the nine species of greatest ecological importance in the FF (Table 2).

Table 2 Importance value index (IVI) of species evolving in the forest types of the Likouala swamp forest (SF)

Species	IVI			
	FF	PFF	TFF	SF
Albizia adianthifolia (Schumach.) W. Wight	0.00	1.37	0.00	0.41
Albizia ferruginea (Guill. & Perr.) Benth.	0.00	0.58	0.00	0.19
Albizia glaberrima (Schumach. & Thonn.) Benth.	0.39	1.98	0.00	0.75
Albizia laurentii (Schumach. & Thonn.) Benth.	0.00	2.42	0.00	0.78
Alchornea floribunda Müll. Arg.	0.30	0.00	0.00	0.10
Alstonia boonei De Wild.	0.31	0.00	0.00	0.10
Amphimas ferrugineus Pierre ex Pellegr.	0.52	0.00	0.31	0.28
Angylocalyx pynaertii De Wild.	2.02	10.39	32.74	15.56
Anthocleista sp.	0.00	0.55	0.00	0.18

Aoranthe cladantha (K. Schum.) Somers	0.00	0.00	0.41	0.14
Barteria fistulosa Mast.	0.00	0.00	0.95	0.31
Blighia sp.	0.00	0.00	2.01	0.67
Blighia unijugata (Hiern) Radlk.	0.30	0.00	0.00	0.10
Canarium schweinfurthii Engl.	0.31	1.26	1.86	1.19
Carapa procera DC.	45.85	1.99	0.00	15.87
Centroplacus glaucinus Pierre	1.31	0.00	0.00	0.43
Chrysophyllum sp.	0.86	0.00	0.00	0.29
Cleistanthus inundatus J. Léonard	0.00	0.00	1.00	0.33
Cleistopholis patens (Benth.) Engl. & Diels	0.01	0.00	0.79	0.27
Cleistopholis sp.	0.30	0.00	0.24	0.19
Coelocaryon preussii Warb.	8.29	3.75	3.75	5.12
Cola ballayi Cornu ex Heckel	0.00	0.00	4.40	1.49
Corynanthe pachyceras K. Schum.	0.00	0.00	0.32	0.10
Dacryodes buettneri (Engl.) H.J. Lam	0.91	0.55	0.00	0.49
Dacryodes normandii Aubrév. & Pellegr.	0.00	0.00	3.14	1.20
Dacryodes sp.	1.96	0.60	0.33	0.97
Daniellia pynaertii De Wild.	0.41	1.77	0.00	0.70
Desplatsia sp.	0.00	0.00	1.13	0.37
Dialium pachyphyllum Harms	2.44	41.61	5.57	16.11
Dialium sp.	1.01	0.00	3.04	1.37
Dichaetanthera sp.	0.00	0.80	0.00	0.26
Dichostemma glaucescens Pierre	0.66	0.00	0.00	0.11
Diospyros crassiflora Hiern	4.42	10.91	2.77	5.98
Diospyros dendo Hiern	2.33	0.00	0.00	0.77
Diospyros mannii Hiern	0.31	0.00	0.63	0.31
Diospyros sp.	0.30	0.00	0.95	0.42
Drypetes occidentalis (Müll. Arg.) Hutch.	21.02	0.00	0.00	6.99
Duboscia macrocarpa Bocq.	0.00	0.00	3.86	1.37
Entandrophragma angolense (Welw.) C. DC.	0.00	0.00	2.69	0.99
Entandrophragma cylindricum (Sprague) Sprague	0.00	0.00	1.86	0.65
Entandrophragma palustre Staner	18.91	0.58	0.00	6.46
Eriocoelum microspermum Gilg ex Radlk.	10.61	12.28	1.51	8.04
Erythrophleum suaveolens (Guill. & Perr.) Brenan	0.00	0.00	0.37	0.12
Garcinia punctata Oliv.	0.00	6.73	13.69	6.84
Garcinia smeathmannii (Planch. & Triana) Oliv.	8.39	0.00	0.00	2.79
Garcinia sp.	2.70	6.15	2.46	3.72
Gardenia imperatis K. Schum.	0.00	3.46	0.00	1.07

Gilbertiodendron dewevrei (De Wild.) J. Léonard	0.00	0.00	49.78	17.65
Grewia oligoneura Sprague	0.63	0.00	0.00	0.21
Grossera macrantha Pax	24.53	10.84	0.00	11.63
Guibourtia demeusei (Harms) J. Léonard	6.25	23.23	0.32	9.28
Hallea stipulosa (DC.) Leroy	2.77	1.45	0.00	1.39
Heisteria sp.	0.00	0.00	0.31	0.10
Indet sp.	2.33	9.96	4.14	5.38
Irvingia gabonensis (Aubry-LeComte ex O'Rorke) Baill*.*	0.00	0.00	0.40	0.24
Klainedoxa gabonensis Pierre ex Engl.	0.00	11.96	9.26	6.93
Leplaea thompsonii (Sprague & Hutch.) E.J.M. Koenen & J. J. de Wilde	0.00	0.00	0.94	0.31
Lophira alata Banks ex C. F. Gaertn.	0.00	32.37	18.39	16.46
Macaranga spinosa Müll. Arg.	0.87	1.23	0.75	0.95
Maesopsis eminii Engl.	0.00	0.00	0.34	0.11
Mammea africana Sabine	1.31	0.00	1.85	1.06
Manilkara fouilloyana Aubrév. & Pellegr.	14.55	2.21	0.50	5.71
Manilkara obovata (Sabine & G. Don) J. H. Hemsl.	4.85	0.00	0.33	1.72
Maranthes sp.	0.31	0.00	0.00	0.10
Massularia acuminata (G. Don) Bullock ex Hoyle	0.00	1.14	3.66	1.61
Milicia excelsa (Welw.) C.C. Berg	0.00	0.00	12.79	4.77
Monodora myristica (Gaertn.) Dunal	0.00	4.18	1.32	1.82
Musanga cecropioides R. Br.	0.00	0.00	0.97	0.35
Panda oleosa Pierre	0.00	1.62	5.45	2.36
Parinari excelsa Sabine	0.00	5.40	0.87	2.01
Pauridiantha sp.	0.00	0.00	0.86	0.30
Pentaclethra macrophylla Benth.	0.00	6.70	7.56	4.80
Petersianthus macrocarpum (P. Beauv.) Liben	0.00	0.99	6.77	2.59
Piptadeniastrum africanum (Hook. f.) Brenan	0.00	0.60	0.00	0.19
Plagiostyles africana (Müll. Arg.) Prain	1.28	13.84	3.86	6.28
Pseudospondia microcarpum (A. Rich.) Engl.	0.00	0.00	2.71	0.96
Pterocarpus soyauxii Taub.	0.00	1.25	0.00	0.38
Pycnanthus angolensis (Welw.) Warb.	0.00	3.28	4.64	2.66
Rhabdophyllum arnoldianum (De Wild. & T. Durand) Tiegh.	0.00	6.51	0.05	2.15
Rhabdophyllum sp.	0.00	0.00	0.95	0.31
Rinorea sp.	0.32	0.66	1.92	0.97
Staudtia kamerunensis Warb.	0.00	5.48	13.48	6.33
Sterculia tragacantha Lindl.	3.66	0.00	0.00	1.21
Strombosia grandifolia Hook. f.	0.00	18.38	28.89	16.00
Strombosiopsis tetrandra Engl.	0.00	9.27	6.09	5.15

Symphonia globulifera L. f.	37.49	0.00	0.00	12.41
Synsepalum subcordatum De Wild.	0.00	0.00	3.03	1.06
Syzygium staudtii (Engl.) Mildbr.	0.00	0.57	0.00	0.18
Terminalia superpa Engl. & Diels	0.00	0.00	2.46	0.90
Tesmania sp.	0.00	0.00	0.78	0.27
Thomandersia sp.	0.00	0.00	0.65	0.22
Treculia africana Decne.	0.53	0.00	0.00	0.18
Tricalysia sp.	0.00	0.78	0.00	0.24
Trichilia gilletii De Wild.	0.00	0.00	0.41	0.14
Trichilia prieuriana A. Juss.	0.00	4.04	0.00	1.22
Trichilia sp.	1.05	0.57	0.42	0.68
Trichilia welwitschii C. DC.	1.42	0.00	0.00	0.46
Trilepisium madagascariensis DC.	0.00	0.57	0.00	0.34
Uapaca mole Pax	34.75	4.21	4.51	14.45
Vitex welwitchii Gürke	0.00	0.00	0.68	0.23
Xylopia aethiopica (Dunal) A. Rich.	6.96	5.01	1.09	4.29
Xylopia hypolampra Mildbr.	0.00	1.95	3.00	1.67
Xylopia rubescens Oliv.	16.37	0.00	0.00	5.43
Xylopia sp.	0.61	0.00	0.00	0.21
Total	300	300	300	300

In the PFF, *Dialium pachyphyllum* had the highest ecological importance value. It was followed by *Lophira alata, Guibourtia demeusei, Strombosia grandifolia, Plagiostyles africana, Eriocoelum microspermum, Klainedoxa gabonensis, Diospyros crassiflora, Grossera macrantha* and *Angylocalyx pynaertii* (Table 2). The species of greatest ecological importance in the TFF were, in descending order: *Gilbertiodendron dewevrei, Angylocalyx pynaertii, Strombosia grandifolia, Lophira alata, Garcinia punctata, Staudtia kamerunensis* and *Milicia excelsa.* For the entire swamp forest studied, *Gilbertiodendron dewevrei, Lophira alata, Dialium pachyphyllum, Strombosia grandifolia, Carapa procera, Angylocalyx pynaertii, Symphonia globulifera, Uapaca mole* and *Grossera macrantha* were the most ecologically important species.

3.2. Forest stand structure

3.2.1. Horizontal structure

The average density is 390±9 stems/ha for the Likouala swamp forest (northern of the republic of Congo). The three facies studied have mean densities of around 445±8, 373±15 and 351±13 respectively in the FF, PFF and TFF, tending to decrease significantly from the FF to the TFF (Figure 1).
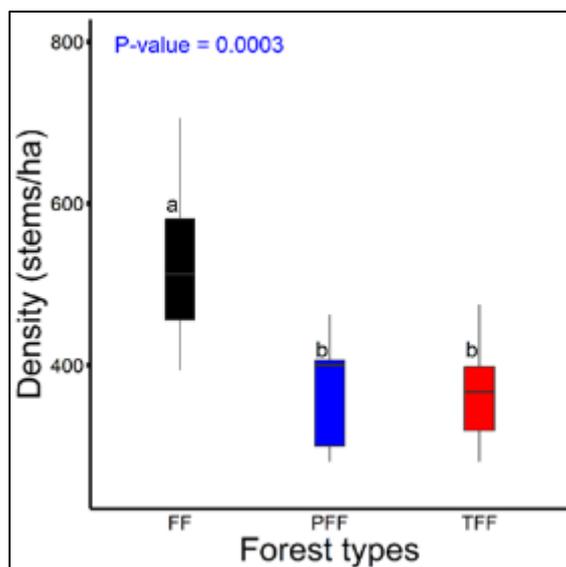
Figure 1 Spatial variability of tree density in the Likouala swamp forest

Basal area data differ between the transects and their characteristic facies studied (Table **3**). The average basal area of the Bondzalé transect is roughly equal to that of the Ekolongouma transect and higher than that of the Itanga transect. The mean basal area decreases in two directions on the three facies studied per transect: Bondzalé (FF<PFF<TFF), Ekolongouma (FF<PFF<TFF) and Itanga (FF>PFF>TFF). The Likouala swamp forest has an average basal area of 32.26±1.5 m²/ha.

Table 3 Basal area (m²/ha) of the different sites (transects) studied

Forest types	Sites			Swamp Forest
	Bondzalé	Ekolongouma	Itanga	
FF	31.00±1.5	29.56±4.6	29.74±1.6	30.00±2.1
PFF	36.08±0.8	33.67±2.7	23.61±1.9	31.12±2.2
TFF	38.18±5.4	38.05±4.5	23.61±2.1	35.46±3.2

3.2.2. Vertical structure

Overall, the Likouala swamp forest has a minimum height of 10.05 m and a maximum height of 43.65 m, with an average height of 22.69±5.43 m (Table 4).

Table 4 Minimum and maximum tree heights on the forest types studied

Forest types	Minimum height (m)	Maximum height (m)	Mean height (m)
FF	10.05	32.85	20.26±4.20
PFF	11.25	35.25	20.19±4.88
TFF	10.65	43.65	26.10±5.82

Maximum tree height and average canopy height increase from flooded forest to terra firme forest.

3.2.3. Diametric structure

The diametric distribution curves for individual trees sampled in the three forest types of the Likouala swamp forest are in the shape of an inverted J (Figure 2).
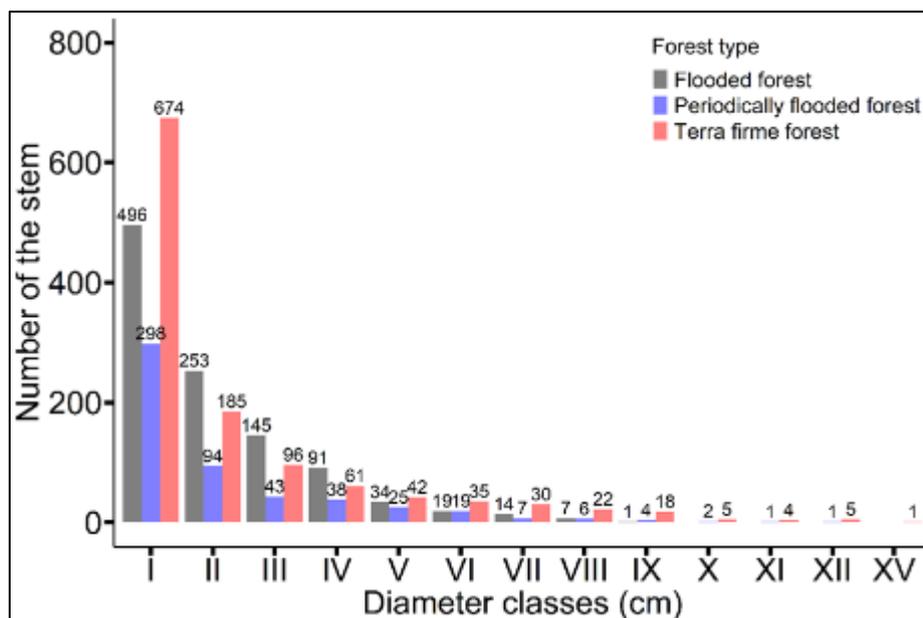
Figure 2 Diametric distribution of trees in the three forest types of the Likouala swamp forest

4. Discussion

4.1. Ecological importance of tree species

A species has a high ecological importance when its importance value index is greater than or equal to 10 per 300 [23]. This dominance is based on the combined values of relative density, relative dominance and relative frequency within the stand studied [22]. The results of this study revealed that the number of dominant species tends to increase as one moves from terra firme forest to flooded forest. In each forest type of the Likouala swamp forest, species of very high ecological importance represent more than 56% of the species recorded. Sciaphyte species, i.e. those that tolerate shade [26], are the best represented in the three forest types. In the peat flooded forest (FF), nine species of high ecological importance make up around 75% of the 50 species recorded. These sciaphytes, notably *Carapa procera, Symphonia globulifera, Grossera macrantha, Drypetes occidentalis, Manilkara fouilloyana* and *Eriocoelum microspermum* clearly dominate over pioneer species such as *Uapaca mole* and *Xylopia rubescens*. In the periodically flooded forest (PFF), ten species with high values of ecological importance account for 62% of the 51 species recorded. As in the FF, shade-tolerant species, notably *Dialium pachyphyllum, Guibourtia demeusei, Strombosia grandifolia, Plagiostyles africana, Eriocoelum microspermum, Diospyros crassiflora, Grossera macrantha* and *Angylocalyx pynaertii*) are dominant over pioneer species such as *Lophira alata* and *Klainedoxa gabonensis*. As for terra firme forest (TFF), seven ecologically important species account for 57% of the 68 species recorded, with a marked predominance of sciaphytes such as *Gilbertiodendron dewevrei, Angylocalyx pynaertii, Strombosia grandifolia, Garcinia punctata* and *Staudtia kamerunensis.* Pioneer species are few in number, being limited to *Lophira alata* and *Milicia excelsa*. The low representation of pioneer species suggests a gradual evolution of each forest type in the Likouala swamp forest towards a mature stage, characterised by a physiognomy dominated by sciaphyte species. Although species with low ecological importance are a priority for conservation [27], a better understanding of the ecology of species with high ecological importance remains essential in order to propose appropriate sustainable management measures.

4.2. Stand structure

The density obtained in FF (445±8 stems/ha) is slightly higher than that found by Lewis et al. [28] in the flooded forests of Central Africa (428 stems/ha) and Africa (426 stems/ha). Lewis et al. [28] also mention that the number of stems per hectare increases from TFF to FF. This difference in density can be explained by the specific composition of each forest type and the capacity for natural regeneration. This regeneration capacity is reflected in the high number of trees with a diameter of less than 70 cm in the FF.

The average basal area obtained in our swamp forest (32.26±1.50 m²/ha) is within the range of values estimated for tropical forests (25.00 - 50.00 m²/ha) [16]. It is close to that found by Lewis et al. [28] in central Africa (30.00 m²/ha). Our basal area value obtained in the FF is higher than that found by Lewis et al. [28]. These differences between the

facies studied and between our results and those found in Central Africa may be linked to the percentage of large-diameter trees and to the different species composition of the different forest types.

The results concerning the vertical structure of the flooded forest are close to those found by Gibert [2] in the Likouala region, although these results concerning the minimum height of the canopy (15.00 m) are higher than those found during the present study (10.05 m). This difference in minimum height can be explained by the length of the transect (9.00 km), which made it possible to avoid edge effects by sampling trees right into the flooded forest dominated by *Raphia laurentii*. In fact, trees growing in flooded forest dominated by *Raphia laurentii* tend to be stunted. This can be explained by the difficult environmental conditions, which lead woody trees to set up adaptation mechanisms [18]. The maximum height of the canopy in our flooded forest (31.20 m) is higher than the 20.00 m found by Evrard [18] and Betbeder et al. [20] in the FF of the central basin. On the other hand, it is close to the maximum stand height of 30.00 m found by Gibert [2] in the FF where *Entandrophragma palustre* is present. The maximum canopy heights of the PFF (35.25 m) and TFF (43.65 m) are close to the values of 30.00 m and 40.00 m reported by Evrard [18] and Betbeder et al. [20] for the PFF and TTF (respectively) in the central Africa. Our transect reveals at a distance of 9.00 km a reduction in the maximum canopy height of our swamp forest stand of around 12 m, starting from FTF (43.65) to FF (31.20 m). This result is roughly equal to that found by Pascal [29] in a swamp forest in India (10.00 m). This reduction in the maximum height of the stand can be explained by the influence of the adaptive constraints to which tree species are subject when faced with a hydromorphic environment (FF). The latter does not allow them to maintain good growth in height, except for certain trees such as *Entandrophragma palustre, Symphonia globulifera* and *Manilkara fouilloyana*.

A study of the diametric structure of the different forest types revealed a regular decrease in the number of trees with each diameter class. This result highlights the existence of several sciaphyte (shade-tolerant) species on the three forest types studied [16]. The "inverted J" distributions, typical of undisturbed tropical forests [16], underline the fact that our swamp forest is not in the process of regression. The stand on each forest type is young. The number of trees with a diameter greater than or equal to 70 cm, which tends to increase from the flooded forest to the terra firme forest, reflects the basal area data found during this study.

5. Conclusion

The floristic and structural characterisation of the three forest types of the Likouala swamp forest was carried out over a study area of 7.06 ha. The ecological functioning of the three forest types studied is based on 7, 9 and 10 species with high values of ecological importance, respectively for the TFF, FF and PFF. The low representation of pioneer species suggests a gradual evolution of each forest type in the Likouala swamp forest towards a mature stage, characterised by a physiognomy dominated by sciaphyte species. The density and basal area values obtained are typical of tropical rainforests and differ significantly between forest types. The minimum and maximum heights of trees on the different facies studied tended to increase from FF to TFF. Diametric distribution curves revealed that the Likouala swamp forest types studied are undisturbed and composed of several sciaphilous species.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

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