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Research Article

Tree Species Diversity, Richness, and Similarity in Intact and Degraded Forest in the Tropical Rainforest of the Congo Basin: Case of the Forest of Likouala in the Republic of Congo

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Trees species diversity, richness, and similarity were studied in fifteen plots of the tropical rainforests in the northeast of the Republic of Congo, based on trees inventories conducted on fifteen 0.25 ha plots installed along different types of forests developed on terra firma, seasonally flooded, and on flooded terra. In all of the plots installed, all trees with diameter at breast height, DBH ≥ 5 cm, were measured. The Shannon diversity index, species richness, equitability, and species dominance were computed to see the variation in tree community among plots but also between primary forest and secondary forest. A total of 1611 trees representing 114 species and 35 families were recorded from a total area of 3.75 ha. Euphorbiaceae was the dominant family in the forest with 12 species, followed by Fabaceae-Mimosoideae (10 species) and Phyllanthaceae (6 species) and Guttiferae (6 species). The biodiversity did not vary greatly from plot to plot on the whole of the study area (3.75 ha). The low value of Shannon index was obtained in plot 11 ($H' = 0.75$) whereas the highest value was obtained in plot 12 ($H' = 4.46$). The values of this index vary from 0.23 to 0.95 in plots P11 and P15, respectively. Results obtained revealed high biodiversity of trees of the forest of Impfondo-Dongou. The information on tree species structure and function can provide baseline information for conservation of the biodiversity of the tropical forest in this area.

1. Introduction

Tropical forests are the subject of several studies to better understand the role they could play in sustainable development, climate change, and floristic biodiversity [1, 2]. Tropical forests provide many goods and ecosystem services, such as prevention of soil erosion and preservation of habitats for plants and animals [3]. Globally, 52% of the total forests are in tropical regions and they are known to be the most important areas in terms of biodiversity [2, 4]. This diversity is an indicator that allows appreciating links between the richness and the abundance of individuals' trees; it reflects the degree of heterogeneity or stability of vegetation [5]. In the Republic of Congo (RoC), according to the definition of the forest, forests cover 69% of the territory [6]. Sustainable management of these forests requires a good knowledge of all the natural forest resource; this knowledge could be reliable only through studies of the forest environment.

Vegetation's studies led to either conducting a physiognomic research of the architectural type or identifying a number of representative reporting vegetation parameters, allowing defining simply, in order to compare it to other vegetation (Lescure, 1985). For the present study, the second approach was used, that of the floristic and structural parameters.

Many tropical forests are under great anthropogenic pressure and require management interventions to maintain the overall biodiversity, productivity, and sustainability [7]. Understanding tree composition and structure of forest is a vital instrument in assessing the sustainability of the forest, species conservation, and management of forest ecosystems [8]. Long-term biodiversity conservation depends basically on the knowledge of the structure, species richness, and the ecological characteristics of vegetation.

Some studies on the knowledge of the plant resource were conducted in Republic of Congo ([9–14] for the massif of Mayombe, [15]), but these studies remained generally piecemeal and predominantly localized inner protected areas and logging forest concessions. These studies were related to the ethnobotanical aspects and general knowledge of the flora of the Republic of Congo. And most of these studies were done essentially in the south of Republic of Congo and just one in the centre-west of our country. This work will provide more information on the tropical forest of Likouala, RoC. The aims of this research paper are to identify and quantify tree forest species of the tropical rainforest of Likouaka and specific objectives are (i) a floristic analysis of the forest of the axis Impfondo-Dongou, Likouala; (ii) analysis of floristic heterogeneity between interforest plots.

The study area is located within the Likouala department, which is of the most important forest regions in Republic of Congo.

2. Material and Methods

2.1. Study Area. The study was carried out within the tropical rainforest of the North of Congo Brazzaville in the department of Likouala (Figure 1). The zone of study covers a total surface of 155274 ha. It lies between 1°27′52,85″ and 2°6′55,76″ of northern latitude and between 17°52′35,04″ and 18°04′32,65″ of longitude.

The climate of the study area is of equatorial type. Mean rainfall is of 1760 mm y^{-1}, with a dry season from December to January and a long wet season from March to November (Figure 2). In the Dongou district, the soil cover is of tertiary clay sandy formation and a quaternary alluvial formation to the east. The soils derived from there are impoverished ferrilitic brown-red clay-sand soils on the Western plateau, ferralitic/hydromorphic alluvial soils on alluvial terraces, and waterlogged peat soils in flooded areas. This area has one of the very low densities of human population (0.93 km^{-2}) of the Republic of Congo. The forest of Likouala contains a high diversity of trees and plants [16]. In the Dongou district, the forests of the study area are rainforest. The principal vegetation types are partially deciduous dense rainforests of Ulmaceae and Sterculiaceae, swampy flooded forest of *Uapaca heudelotii*, and forest of *Guibourtia demeusei* [17]. Tree canopy closure of the forest varies from 93% to 100% while the tree height varies from 30 m to above 45 m (own data).

Table 1: Distribution of number of plots inside each type of forest.

Type of forest	Plots	Number of trees	Density (n/ha)	G (m^2/ha)
DF[1]	P1	67	268	6.75
	P2	73	312	9.11
	P3	212	848	34.24
	P11	217	868	26.73
PF[2]	P5	115	460	23.06
	P6	103	412	25.88
	P7	64	256	36.37
	P8	70	280	30.80
	P9	36	144	16.01
	P10	115	460	29.20
	P4	133	532	36,38
	P12	132	528	29.51
	P13	162	648	35.54
	P14	121	484	21.60
AF[3]	P15	51	204	36.52

1: degraded forest; 2: primary forest; 3: agroforestry.

2.2. Data Collection. The tree sampling for the data collection was performed in 15 plots of 50 m × 50 m each placed in different forest strata of the study area: primary forest, secondary forest, and a mosaic of primary and secondary forest (Figure 3). Table 1 indicates the distribution of plots on the extent of the zone of study. The plot of intact forests and degraded forests inventoried was selected after image processing Landsat (OLI 8) of the study area. Coordinates GPS of the zones chosen on the satellite images were recorded in a GPS and on the ground we used the function Goto to go towards the points selected for the installation of the plot of inventories. The ground data allowed validating the classification of different type of forest in primary forest and secondary or degraded forest but also of the forest agro plot. Four plots fell into the zone from forest degraded, ten plots fell in the primary forest, and 1 plot fell into an agro drill forest.

GPS points of all plots were recorded, and inside each plot all living trees with diameter at breast height (DBH) ≥ 5 cm were recorded by species using latest botanical classification. All tree species were assigned to families and relative diversity (number of species in a family) was obtained for tree species diversity classification.

2.3. Measuring Biodiversity. We apply the Shannon diversity index (H') as a measure of species abundance and richness to quantify diversity of the woody species. This index takes both species abundance and species richness into account:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i, \quad (1)$$

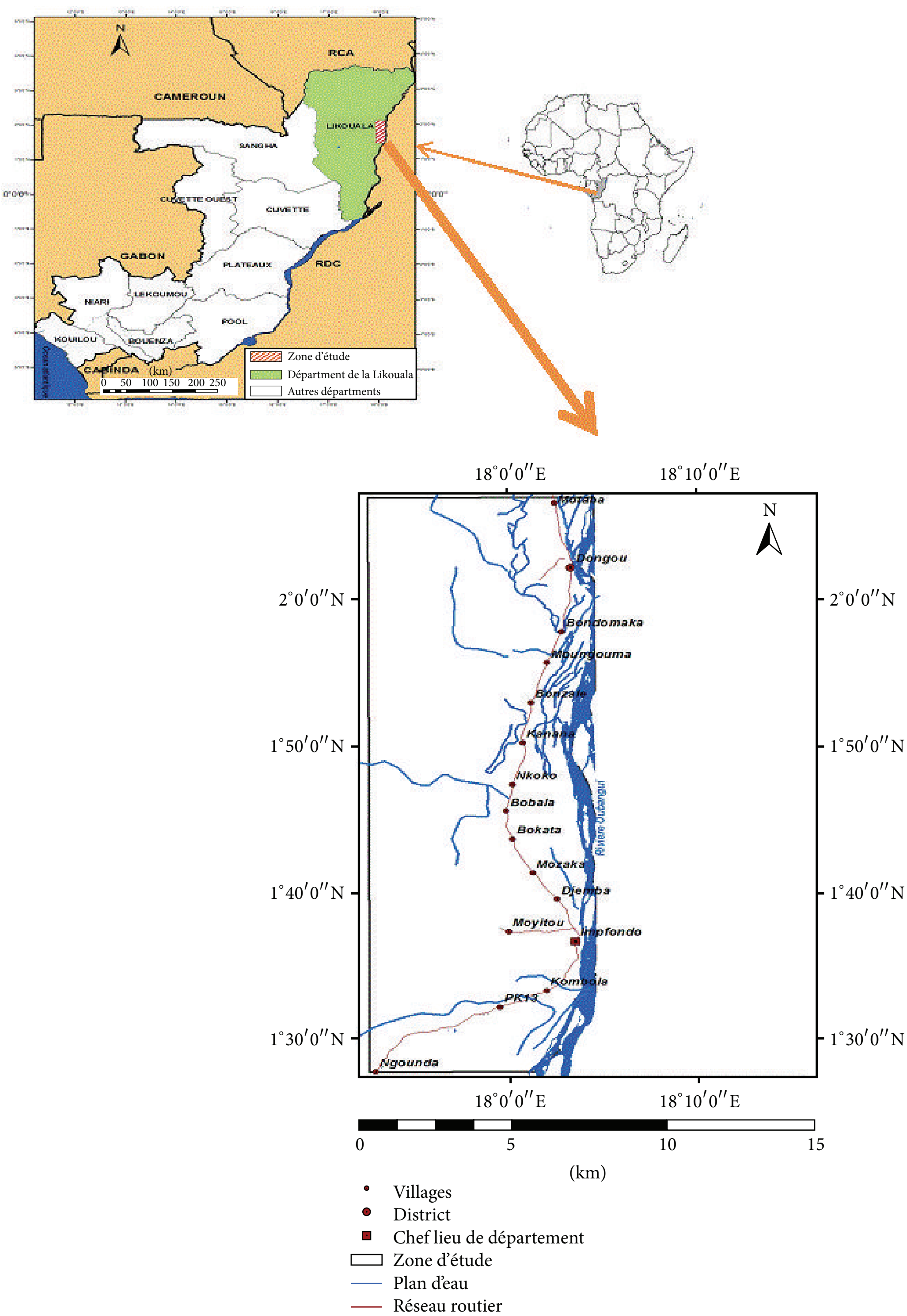

Figure 1: Localization of the department of Likouala, Congo Brazzaville.

where s equals the number of species and p_i equals the ratio of individuals of species i divided by all individuals N of all species. The Shannon diversity index ranges typically from 1.5 to 3.5 and rarely reaches 4.5 [18].

The variance of H' is calculated by

$$\operatorname{var} H' = \frac{\sum p_i (\ln p_i)^2 - \left(\sum p_i \ln p_i\right)^2}{N} + \frac{s-1}{2N^2} \qquad (2)$$

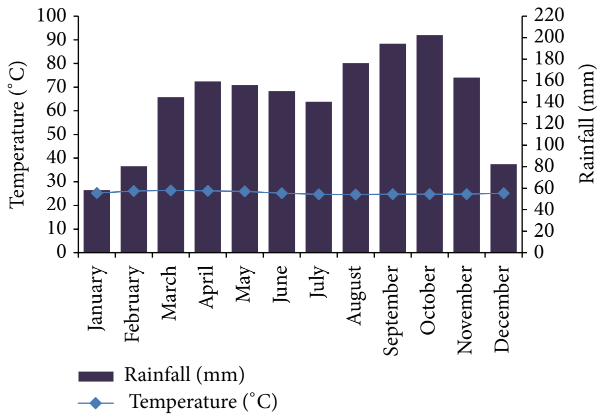

FIGURE 2: Ombrothermic diagram of Likouala (data from 1932 to 2015), ANAC Congo.

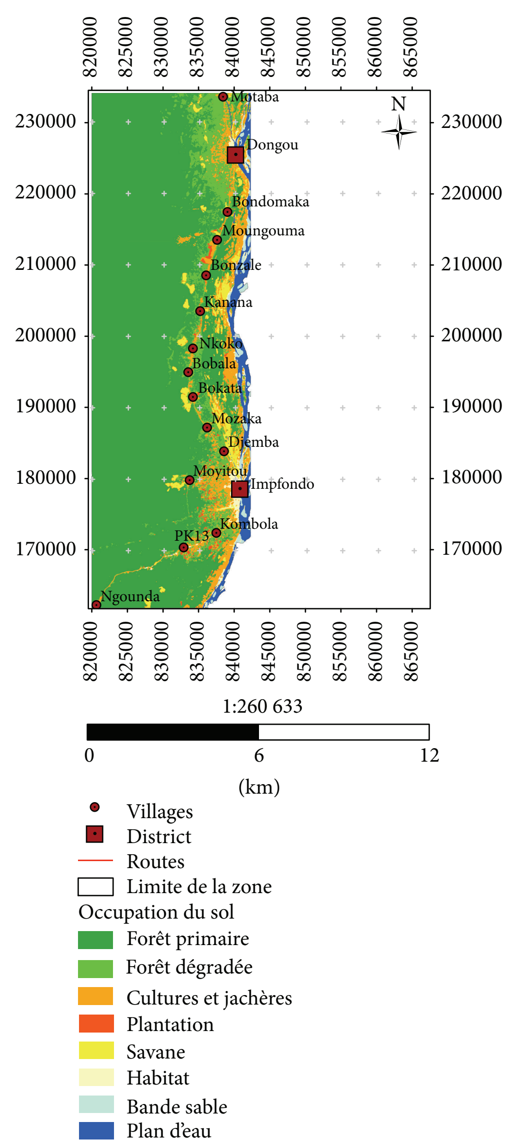

FIGURE 3: Cartography of land use change inside study's area.

and a t-statistic to test the significant differences between two plots or samples as

$$t = \frac{H_1' - H_2'}{\sqrt{\operatorname{var} H_1' + \operatorname{var} H_2'}}, \tag{3}$$

where H' is the Shannon diversity index of sample j.

Degrees of freedom for this test are equal to

$$\text{d.f.} = \frac{\left(\operatorname{var} H_1' + \operatorname{var} H_2'\right)^2}{\left(\operatorname{var} H_1'\right)^2 / N_1 + \left(\operatorname{var} H_2'\right)^2 / N_2}, \tag{4}$$

where N_1 and N_2 are the number of individuals in samples 1 and 2, respectively [19]. We have also considered the Simpson index (D), a measure of species dominance, and the Shannon diversity index (E), a measure of evenness of spread.

The Simpson index is defined as

$$D = \sum_{i=1}^{s} \left(\frac{n_i (n_i - 1)}{N (N - 1)} \right), \tag{5}$$

where n_i is the number of individuals in the ith species and N equals the total number of individuals. As biodiversity increases, the Simpson index decreases. Therefore to get a clear picture of species dominance, we used $D' = 1 - D$.

The Shannon-Wiener index is defined as

$$E = \frac{H'}{H_{\max}} = \frac{-\sum_{i=1}^{s} p_i \ln p_i}{\ln s}. \tag{6}$$

$H'_{\max}$ is the natural logarithm of the total number of species. A value for evenness approaching zero reflects large differences in abundance of species, whereas an evenness of one means all species are equally abundant:

$$\text{Margalef' Index } (d) = \frac{(S - 1)}{\ln (N)}, \tag{7}$$

where S is the total number of species, "N" is the number of individuals, and "ln" is the natural logarithm.

2.4. Similarity. The Jaccard index was used to calculate similarities of species between the forest types in different forest fragments. These coefficients are used to measure the association between samples. The similarity of two samples (floristic sample) is based on the presence or absence of certain species in the two samples [20]. To study the similarity of our different floristic samples, we used two binary factors excluding the double zeros, that is, the coefficient of Sorensen (K) and the coefficient of Jaccard (S). The Sorensen coefficient provides a twice higher weight to double presence; we can consider the presence of a more informative than this absence [20]:

$$S\,(\%) = \frac{(a \times 100)}{(a + b + c)}$$
$$K\,(\%) = \frac{(2a \times 100)}{(2a + b + c)} \tag{8}$$

Table 2: Floristic lists and their frequencies of the study area.

Family	Scientific name	Number of species	Number of trees
Achariaceae	*Caloncoba welwitschii* (Oliv.) Gilg.	1	9
Anacardiaceae	*Pseudospondias microcarpa* (A. Rich.) Engl. *Trichoscypha acuminata* Engl.	2	14
Annonaceae	*Anonidium mannii* (Oliv.) Engl. & Diels *Monodora angolensis* Welw.	2	19
Apocynaceae	*Alstonia boonei* De Wild.	1	1
Aptandraceae	*Ongokea gore* (Hua) Pierre	1	1
Bignoniaceae	*Markhamia tomentosa* (Benth.) K.	1	1
Burseraceae	*Dacryodes pubescens* (Verm.) Lam.	1	3
Cannabaceae	*Celtis adolfi-friderici* Engl.	1	12
Chrysobalanaceae	*Parinari congensis* F. Didr. *Parinari congolana* T. Durand et H. Durand *Parinari excelsa* Sabine *Maranthes glabra* (Oliv.)	4	32
Combretaceae	*Terminalia superba* Engl. et Diels.	1	3
Ebenaceae	*Diospyros crassiflora* Hiern *Diospyros ituriensis* (Gùrke) R. Let et F. White	2	47
Euphorbiaceae	*Cleistanthus itsogohensis* Pellegr. *Croton haumanianus* J. Léonard *Dichostemma glaucescens* Pierre *Grossera macrantha* Pax *Macaranga barteri* Mull.-Arg. *Macaranga monandra* Mull.-Arg. *Macaranga schweinfurthii* Pax *Macaranga spinosa* Mull.-Arg. *Plagiostyles africana* (Mull.-Arg.) Prain *Ricinodendron heudelotii* (Baill.) Pierre ex Pax *Sapium ellipticum* (Hochst.) Pax *Tetrorchidium didymostemom* (Baill.) Pax & K. Hoffm.	12	239
Fabaceae-Caesalpinioideae	*Copaifera salikounda* Heckel *Daniellia pynaertii* De Wild. *Dialum pachyphyllum* Harms *Guibourtia demeusei* (Harms) Léon. *Swartzia Bobgunnia fistuloides* (Harms) G.H Kirkpr.	5	116
Fabaceae-Faboideae	*Angylocalyx pynaertii* De Wild. *Baphia dewevrei* De Wild. *Millettia sanagana* Harms *Pterocarpus soyauxii* Taub.	4	123
Fabaceae-Mimosoideae	*Albizia ferruginea* (Guill. & Perr.) Benth. *Albizia laurentii* De Wild. *Cathormion rhombifolium* (Benth.) Hutch. & Dandy (syn: *Albizia rhombifolia* Benth.) *Albizia zygia* (DC) J. F. Macbr. *Newtonia devredii* G. C. C. Gilbert	10	58

Table 2: Continued.

Family	Scientific name	Number of species	Number of trees
	Parkia filicoidea Welw. ex Oliv. *Parkia bicolor* A. Chev. *Pentaclethra macrophylla* Benth. *Piptadeniastrum africanum* (Hook. F.) Bren. *Tetrapleura tetraptera* (Schum. & Thonn.) Taub.		
Guttifereae	*Allanblackia floribunda* Oliv. *Garcinia punctata* Oliv. *Garcinia ovalifolia* Oliv. *Mammea africana* Sabine *Symphonia globulifera* L. f. *Garcinia smeathmannii* Oliv.	6	55
Irvingiaceae	*Irvingia excelsa* *Irvingia grandifolia* (Engl.) Engl. *Klainedoxa gabonensis* Pierre ex Engl.	3	16
Lamiaceae-Viticoideae	*Vitex pachyphylla* Bak.	1	8
Lauraceae	*Persea americana* L.	1	1
Lecythidaceae	*Petersianthus macrocarpus* (P. Beauv.) Liben. *Brazzeia congensis* Baill.	2	63
Malvaceae-Sterculioideae	*Cola nitida* (Vent.) Schott & Endl.	1	2
Malvaceae-Tilioideae	*Duboscia macrocarpa* Brocq.	1	8
Meliaceae	*Carapa procera* var. *palustre* DC *Carapa procera* var. *procera* DC *Entandrophragma cylindricum* (Sprague) Sprague *Trichilia monadelpha* (Thonn.) J. J. De Wild. *Trichilia tessmannii* Harms	5	46
Moraceae	*Antiaris toxicaria* var. *welwitschii* Lesch. *Ficus exasperata* Vahl. *Ficus vogeliana* (Miq.) Miq. *Milicia excelsa* (Welw.) C. C. Berg *Trilepisium madagascariense* DC.	5	17
Myristicaceae	*Coelocaryon preussii* Warb. *Pycnanthus angolensis* (Welv.) Exell *Staudtia kamerounensis* Warb. var. *gabonensis* Fouilloy	3	226
Ochnaceae	*Lophira alata* Banks ex Gaertn. *Rhabdophyllum welwitschii* Van Tiegh.	2	14
Olacaceae	*Heisteria parvifolia* Smith *Strombosia grandifolia* Hoof. F. *Strombosia pustulata* Oliv.	3	52
Pandaceae	*Panda oleosa* Pierre	1	6
Passifloraceae	*Barteria fistulosa* Mast.	1	1
Putranjivaceae	*Drypetes pellegrini* Léandri *Drypetes leonensis* (Pax) Pax et K. Hoffm.	2	7

Table 2: Continued.

Family	Scientific name	Number of species	Number of trees
Phyllanthaceae	*Cleistanthus mildbraedii* Jabl. *Hymenocardia ripicola* J. Léonard *Hymenocardia ulmoides* Oliv. *Maesobotrya dusenii* (Pax) Hutch. *Uapaca guineensis* Mull.-Arg. *Uapaca heudelotii* Baill.	6	37
Rubiaceae	*Aidia micrantha* (K. Schum.) F. White *Colleactina papalis* N. Hallé *Massularia acuminata* (G. Don) Bullock ex Hoyle *Morelia senegalensis* A. Rich. *Morinda pynaertii* Benth. *Oxyanthus schumannianus* De Wild. et Th. Dur *Psydrax subcordata* DC *Psydrax arnoldiana* (De Wild.)	5	44
Rutaceae	*Zanthoxylum heitzii* (Aubrév. & Pellegr.) P. G. Waterman	1	1
Sapindaceae	*Blighia welwitschii* (Hiern) Radlk. *Eriocoelum microspermum* Radlk. *Lecaniodiscus cupanioides* Planch. ex Benth. *Pancovia pedicellaris* Radlk. & Gilg	4	55
Sapotaceae	*Chrysophyllum beguei* Aubrév. *Synsepalum brevipes* (Baker) TD Penn *Tridesmostemom omphalocarpoides* Engl. *Manilkara* sp. *Manilkara fouilloyana* Aubr. et Pellegr.	4	18
Thomandersiaceae	*Thomandersia hensii* De Wild.	1	21
Urticaceae	*Musanga cecropioides* R. Br. *Myrianthus arboreus* P. Beauv.	2	235
	Total	114	1611

with a = number of common presences for both floristic samples, b = number of presences in the first floristic sample, c = number of presences in the second floristic sample, and d = number of species absent in both floristic samples.

According to L. Legendre and P. Legendre [20], the Sorensen coefficient is fully compared with the Jaccard coefficient; that is, if the similarity of a pair of objects computed by the Jaccard coefficient is higher than the similarity of another pair of objects, it will also be higher if we use the coefficient of Sorensen for the calculation of similarity.

3. Results

3.1. Floristic Composition and Species Richness. A total of 1611 trees representing 114 species and 35 families were identified from the total area (3.75 ha). Euphorbiaceae was the dominant family in the forest with 12 species, followed by *Fabaceae Mimosoideae* with 10 species. In terms of the number of trees individuals per family, Euphorbiaceae was the dominant in the whole forest with 239 trees, followed by Urticaceae with 235 trees (Table 2).

In terms of characterization of forest type, this inventory allowed distinguishing several forest types like *Lophira alata*, *Uapaca heudelotii*, *Guibourtia demeusei*, and *Celtis adolfi-friderici*. Inventories have revealed the existence of three vertical strata, whose upper stratum is dominated by species referred to above.

The biodiversity did not vary greatly from plot to plot on the whole of the study area (3.75 ha). A low Shannon diversity index value was obtained in plot 11 ($H' = 0.75$) whereas the highest value was obtained in plot 12 ($H' = 4.46$). A statistical analysis made by launched ANOVA revealed that plot 11 was significantly different to the other plots ($\alpha = 0.05$). A great difference was also noted in biodiversity between secondary plots and primary plots (Table 3). The evenness index was calculated. The values varied from 0.23 in plot P11 to 0.95 in plot P15.

The evenness index E was calculated for each plot. The value of equitability varied from 0 to 1. It is equal to 1 when all

Table 3: Biodiversity values by biodiversities index and static parameters.

Plots	Type of forest	Total individual	*S*	Shannon diversity index (*H*)	Fisher's α	Simpson index	Evenness index = H'_{max}	Variances (*H*)	Ecartype
P1	Degraded forest	67	*26*	4.33	15.76	0.05	3.06	0.28	0.53
P2	Degraded forest	79	*22*	3.54	13.99	0.14	2.64	0.18	0.43
P3	Degraded forest	212	*38*	4.13	23.23	0.08	2.62	0.09	0.3
P4	Primary forest	132	*26*	3.57	14.92	0.14	2.52	0.11	0.34
P5	Primary forest	111	*24*	3.97	11.3	0.08	2.88	0.15	0.39
P6	Primary forest	102	*29*	4.14	17.39	0.07	2.83	0.18	0.42
P7	Primary forest	52	*15*	3.36	8.39	0.11	2.86	0.23	0.48
P8	Primary forest	61	*9*	2.46	3.81	0.22	2.58	0.11	0.33
P9	Primary forest	34	*12*	2.93	8.13	0.16	2.72	0.28	0.53
P10	Primary forest	106	*27*	3.94	16.32	0.09	2.76	0.16	0.4
P11	Degraded forest	217	*10*	0.75	5.85	0.05	0.75	0.04	0.2
P12	Primary forest	126	*33*	4.47	17.76	0.05	2.94	0.16	0.41
P13	Primary forest	153	*31*	3.89	19.03	0.1	2.61	0.11	0.33
P14	Primary forest	109	*31*	4.38	16.54	0.06	2.93	0.18	0.43
P15	Agroforestry	47	*20*	4.12	11.37	0.04	3.17	0.36	0.6

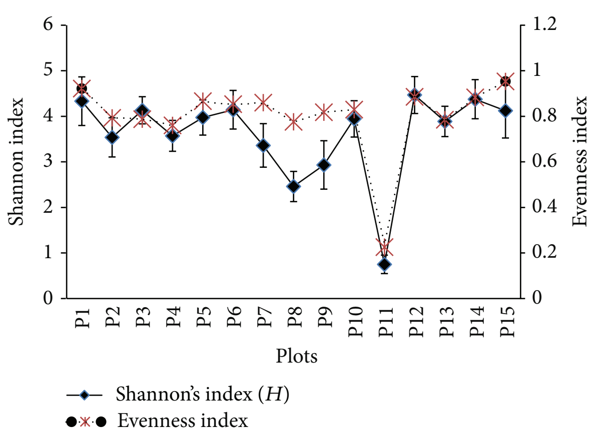

Figure 4: Shannon diversity index and evenness index trends in all the study areas.

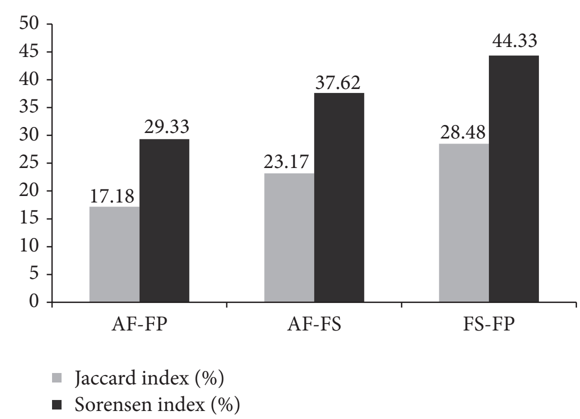

Figure 5: Similarity index between two types of forest. AF = agroforestry, FP = primary forest, and FS = secondary forest.

the species have same abundance and tend towards 0 when the near total of flora is concentrated on only one species. The values of this index varied from 0.23 to 0.95 in plots P11 and P15, respectively (Figure 4). The value of plot 11 confirms well conducted survey in the plot which is dominated by one species, *Musanga cecropioides*. The *E* value obtained in plot P11 is the one with a value inferior to 0.5 out of the entire results. Two plots have value of *E* superior to 0.9 (plots P1 and P15). Twelve plots have a value of *E* varying between 0.7 and 0.89.

3.2. Biodiversities Indexes and Other Parameters. Other analyses of the biodiversity made by applying the other indices such as the index of Fisher α revealed interesting information. Whereas with the Shannon diversity index, it is in plot 11 that we noted the weakest biodiversity, the application of the index Fisher α (Table 3) showed that the low value of the biodiversity was obtained in plot 08 which is a primary forest plot whereas the strongest value of *F* is observed in P3 plot, which is a mosaic of secondary and primary forest. Plot 11 (monodominant plot of *Musanga cecropioides*) does not have the low value of the biodiversity like Shannon diversity index revealed.

The species richness of 114 species was observed in 3.75 ha of the Likouala Forest Department. *Musanga cecropioides* was the most dominant with 222 trees censured followed by *Staudtia kamerounensis* var. *gabonensis* with 117 trees.

3.3. Similarity: Sorensen (K) and Jaccard (S) Index. Species similarities between the forest types were studied between primary forest and secondary forest (FS-FP), primary forest and agroforestry land (AF-FP), and agroforestry land and secondary forest (plot 15). We have noted that the lowest Jaccard index value was obtained between AF-FP (Figure 5) (17.18%). The highest value was noted between FS-FP.

Table 4: The characteristics of ecological factors in some forests of Republic of Congo.

Name of forest	Rainfall (mm)	Authors	Length of dry season
Forest of Impfondo-Dongou	1800–2000	Our study	2
Forest of Mayombe	1600	Koubouana et al. [21]	4
Forest of centre-west of Congo	2132.6	Our own data	2
Forests of the littoral	1500	Kimpouni [22]	4

The indices of diversity enabled us to conclude that the studied zones are rich in cash. Are various studied forests similar from the floristic composition point of view?

The values of coefficient of similarity vary from 17.18% to 28.48% for the index of Jaccard and 29.33% to 44.33% for the index of Sorensen.

4. Discussion

The analysis of the tree flora of the study area showed that the families of Euphorbiaceae (10.53%) are the most represented, followed by the Fabaceae-Mimosoideae (8.77%), Rubiaceae (7.89%), and the Guttiferae (6.14%). Indeed, the presence of the Euphorbiaceae and Rubiaceae generally represented by species of wood is a character common to all tropical rainforests as noted by Reynal-Roques [29]. However the abundance of the Fabaceae-Mimosoideae and Guttiferae is proof of the old age or maturity of the inventoried forest [11]. From the point of view of physiognomy of forest areas studied, the results show that these are the Euphorbiaceae (14.84%) which are abundant in terms of number of trees from beneath wood and stratum average, followed by the Urticaceae (14.59%), the Myristicaceae (14.03%) of the Fabaceae-Faboideae (7.64%), and Fabaceae-Mimosoideae (7.20%). The abundance of the Urticaceae is explained by the presence of quasi-monospecific stands to *Musanga cecropioides* in degraded forests. However the abundance of the Myristicaceae and Fabaceae is a specific character of the forests studied axis Impfondo-Dongou. Indeed, the results obtained in our study are totally different from those obtained by Kimpouni [22] in Congolese coastal forests, Koubouana et al. [30] in the forest of Western Centre at Mbomo and Kelle. Indeed the work of Kimpouni [22] performed in the littoral showed an abundance of the Fabaceae-Caesalpinioideae, followed by the Rubiaceae and Euphorbiaceae. Those of Koubouana et al. (in press) in the centre-west of the Congo showed an abundance of the Fabaceae-Caesalpinioideae (18.05%), followed by the Meliaceae (7.52%), Fabaceae-Mimosoideae (6.02%), Euphorbiaceae (5.26%), Annonaceae (4.51%), and the Myristicaceae (3.76%). In the study conducted at the Mayombe in the South of Congo by Koubouana et al. [21], the results obtained show an abundance of family Burseraceae (19.17%) followed by the Fabaceae-Caesalpinioideae (16.09%), Myristicaceae (13.18%), Annonaceae (9.49%), Euphorbiaceae (8.32%), and Fabaceae-Mimosoideae (7.32%). This variation of the floristic composition of the different forests studied is explained by the diversity of geological substrate and the diversity of climate (Table 4). Table 5 showed the characteristics of ecological factors in the forests studied.

It is important to note that Brazzaville is in the south of the Republic of Congo and Mbomo-Kelle's locality is in the northwest of Republic of Congo. In comparison with these two localities, our study area is in the extreme northeast. Each of the study areas has a local climatic condition (Table 4).

Table 3 shows the values for the assessment of the biodiversity of trees surveyed in 15 parcels that were the subject of this study on floristic biodiversity on ≥10 cm DBH trees. In this study we wanted to focus our attention on the biodiversity indices to assess the level of biodiversity across the study area, but also the microvariations that would exist between the plots of the study area. Moreover, in the scope of this study, we tested the role that vegetation indexes might play in the evaluation of forest degradation between primary and secondary forests.

Considering the Shannon diversity index, our study showed that plot 15 has a lower Shannon index of 1, while two plots have clues to Shannon between 2 and 3. The rest of the plots with higher values have 3. High species richness is a hallmark of many tropical forests (Gentry et al. 2010).

Our study revealed the existence of variability of biodiversity in the study area. According to Orth and Colette [31] the Shannon diversity index has strong values for species with recoveries of same importance and it takes low values, when some species have strong recoveries.

Low biological diversity noted in plot 11 ($H' = 0.75$) could be explained by the fact that it is dominated by a single species *Musanga cecropioides*. This species contributes nearly 90% of the total number of trees in the plot. In two plots with the highest values, the plots contain more than 30 species of trees with at least two species of codominant trees, but with lower contributions. In parcel 12 ($H' = 4.47$), *Angylocalyx pynaertii* De Wild and *Plagiostyles africana* species each have a 13% contribution. In these same plots the other two species following in terms of specific contribution are *Grossera macrantha* and *Strombosia grandifolia* with, respectively, 7% and 6% of a total of 126 species inventoried in this plot. As shown in Table 1, the application of the other indices of biodiversity gives a different result. The Pioulou biodiversity index (H'_{max}) indicates that plot 15 ($H'_{max} = 3.17$) has the highest biodiversity followed by plot 1 ($H'_{max} = 3.06$) and plot 12 ($H'_{max} = 2.94$). Several causes could explain variations in the degree of biodiversity between the plots of the study area: soil type, rainfall trends, anthropogenic action, land use change, and so forth.

The Shannon diversity index values obtained in this study are lower than those obtained in other studies both in the Republic of Congo and in other tropical forests in the Congo basin compared to other tropical countries. For

Table 5: The characteristics of ecological factors in some forests of Republic of Congo.

Type of vegetation	Minimum tree DBH	Study area (ha)	Countries	Rainfall mean (mm/year)	Shannon-Wiener index (bit)	Number of families	Number of genera	Number of trees	Number of species	Authors
	DBH ≤ 10 cm	1.5		1200–1500	1.9 ± 0.5	47	120		153	Kimpouni et al. [23]
Forest	DBH ≥ 20 cm	35	Southwest of the Republic of Congo	1600	3.75	41		5076		Koubouana et al. [21]
Shrub savannah		400	Plateaux Teke, Republic of Congo	1600–2100	2.16	15	16	3075	25	Mampouya Wenina [24]
Fabaceae-Caesalpinioideae	DBH ≥ 20 cm	88.5	Northwest of Republic of Congo	1900	5.3	31	107	11012	133	Koubouana et al. (in press)
Forest	DBH ≥ 10 cm		Plateau des Cataractes, Republic of Congo	1400–1600 mm		42	116		153	Kimpouni [22]
Forest (monodominant *Aucoumea klaineana*)	DBH ≥ 10 cm		Youbi	1200				1186	71	Kimpouni et al. [25]
Mosaics of natural forest and grassland	(DBH) ≥ 10 cm	0.72	Uganda, Youbi, Republic of Congo (southwest)	1397–1500 mm	4.02	26			93	Nangendo et al. [26]
	DBH ≥ 15 cm	1		1300	3.55, 3.47, 3.48, and 3.32	40	73	1789	92	Premavani et al. [27]
Forest	DBH ≥ 10 cm	1.96		2500–3000	3.795			808	72	Aigbe and Omokhua [28]

instance, in the forest of centre-west of Republic of Congo in Mbomo-Kelle (Republic of Congo), Shannon diversity index varies from 5.91 to 5.95 in bloc 4 and bloc 9, respectively (Koubouana et al. in press). In the southwest of the Republic of Congo, studies were conducted by Kimpouni et al. [23] and Koubouana et al. [21] and revealed different H' values. Kimpouni et al. [23] in a degraded forest in Brazzaville obtained for woody species a Shannon diversity index of 1.9 bits. But in the tropical forest of southwest of the Republic of Congo, Koubouana et al. (in press) noted an old secondary forest that the Shannon diversity index was about 3.08.

Regarding heterogeneity, many authors think that the structural heterogeneity of the forests and their high species richness are often interpreted in terms of forest dynamics and relationship with the resulting phenomena of succession [5, 32]. In this work, we have mainly focused on the study of the biodiversity of trees to make a comparison between the degraded forest areas and nondegraded forest areas.

Several factors could explain the variations of biodiversity in our study: the topography of the area [33, 34] or edaphic factors [35, 36] to explain the issue of floral heterogeneity of tropical forests. In our study area, three forest types were identified: flooded forests, solid ground forest, and partially flooded forest. In the context of this work we have studied the differences that exist between forest types through the Jaccard and of Sorensen similarity indexes. Moreover, (K) and Jaccard (S) index give a very good idea of the presence or absence of species in the different transects of the inventory. The range of this coefficient is between 0 and 1. Interpretation of the CSJ values is as follows: 1: both survey sites have only common species; 0: both survey sites have only singular species; 1/2: the two survey sites have as many common species as the sum of singular species at each survey site; [0, 1/2]: the similarity in terms of species diversity between both survey sites is rather low; [1/2.0]: the similarity in terms of species diversity between both survey sites is rather high.

In our case, it ranges from 17.18 to 23.48%, taking into account the three combinations (AF-FP, AF-FS, and FS-FP). This means the similarity in terms of species diversity between both survey sites is rather low. The results showed that there is a high tree biodiversity in our study area.

The values of similarity index are lower than 50%, which enables us to conclude that there is obviously a difference in point of floristic composition between the primary forests and the secondary forests, thus confirming the floristic data that we presented above.

4.1. Evaluation of Forest Degradation through the Biodiversity Indexes. Degradation is considered to be a temporal process. There is however a consensual definition that is accepted by the various stakeholders, which is as follows: forest degradation is the reduction of the capacity of the forest to provide goods and services. In the context of REDD+, forest degradation can be defined as the partial loss of biomass due to logging or other causes of removal of wood from biomass [37]. A degraded forest is a secondary forest that has lost, as a result of human activities, the structure, function, composition, or productivity of species normally associated with a natural forest. Thus, a degraded forest offers a supply of goods and services and has only limited biodiversity. Biological diversity in a degraded forest includes many nontree components which can dominate the understory vegetation cover (CBD (2005; 2001).

To assess the level of forest degradation, a maximum biodiversity index has been applied and presents different values between the secondary and primary forest. These forests are characterized by a very high biodiversity, especially in the case of secondary forests of *Macaranga spinosa* or *Macaranga barteri*. In the case of plots P1 and P2 the objective of this study is to identify settings that allow assessing forest degradation.

5. Conclusion

The study of the biodiversity of the Likouala forests and the Impfondo-Dongou axis revealed a high floral biodiversity of trees considering a diameter of 5 cm at DBH 1.30 m. Tree biodiversity is very important in primary forests. In secondary forests, the biodiversity varies in line with the secondary forest type: secondary forest of *Macaranga spinosa* or secondary forest of *Musanga cecropioides*. Moreover, biodiversity varies according to the nature of the substrate: forest on dry land, forest in partially flooded areas, and flooded forest.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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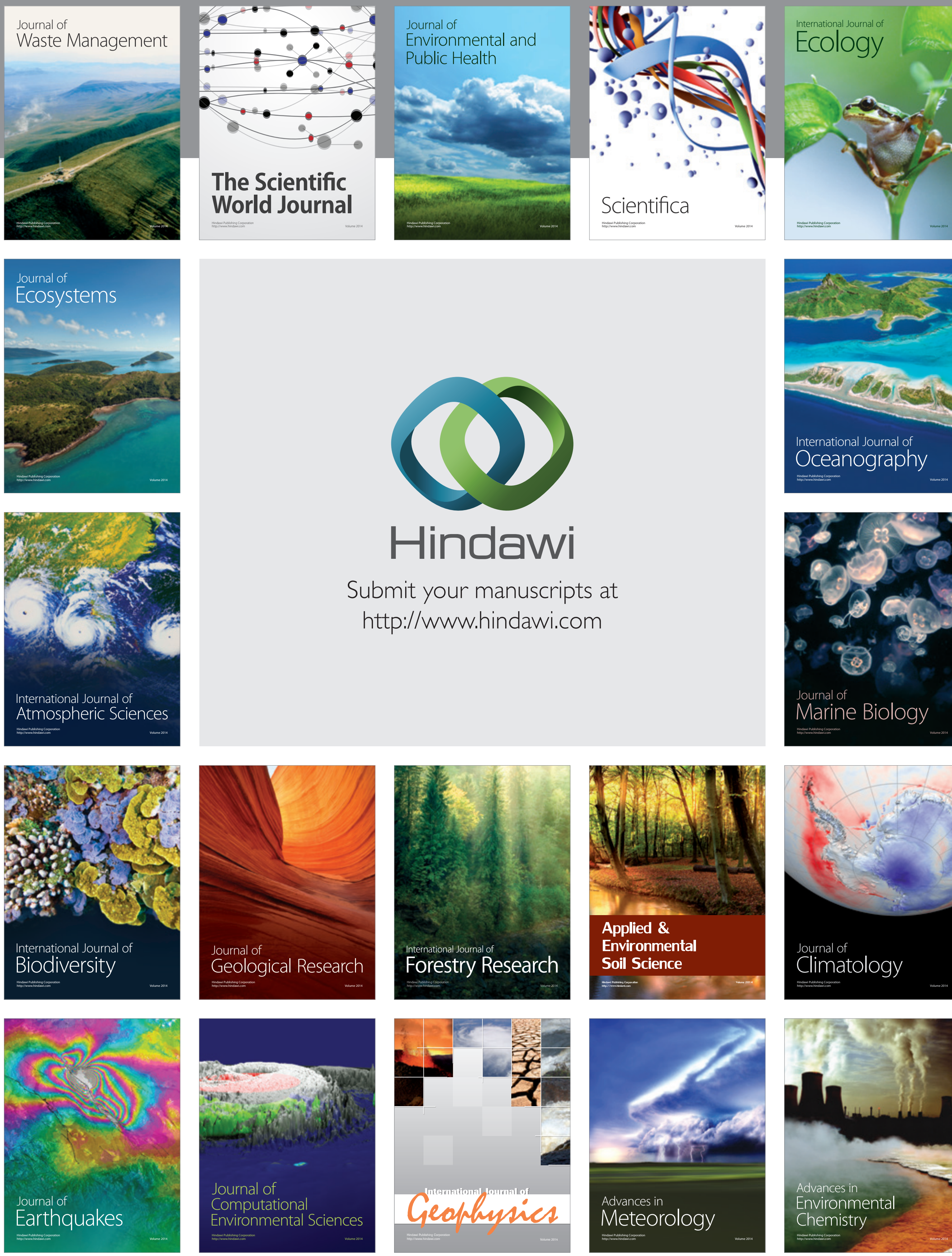
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