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Spatial Analysis of the Woody Flora of the Djoumouna Peri-urban Forest, Brazzaville (Congo)

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Abstract: The spatial analysis of the flora of the peri-urban forest of Djoumouna has been conducted in Brazzaville, Congo. Data collection, conducted from April to August 2017, is based on a floristic inventory of 75 plots of each 400 m^2 (20 m x 20 m). The study shows 898 trees of dbh ≥ 10 cm corresponding to 106 species and 36 families. The number of individuals per plot averages 11.97 ± 0.42 feet/plot while the number of species per plot averages 7.37 ± 0.30. The land used by projecting the trunk sections is on average 0.74 ± 0.05 m^2/plot. The Jaccard similarity coefficient between plots is between 0 and 75% while the average Skewness is 1.26 ± 0.11. The average Shannon index is 1.77 ± 0.05 per plot with an average maximum diversity of 1.93 ± 0.04. The average Pielou index is 0.91 ± 0.01. The absolute diversity index averages 6.54 ± 0.29 while α-Fisher averages 11.44 ± 1.39. The average value of the Green index is -0.04 ± 0.01 and finally 7.55% of taxa have a rarefaction index of species between 40 and 77% compared to 92.45% where this index varies from 81 to 99%. The upward hierarchical classification and the AFC highlight the presence of floristic subfacies resulting from taxa independence. Since most species have a density of less than 1 tree.ha^{-1}, the floristic composition is heterogeneous, resulting in insufficient natural regeneration and low resilience of this ecosystem threatened with extinction in the very short term.

Keywords: Congo, Peri-urban Forest, Plant Diversity, Bio-Ecological Diversity Indices, Structural Parameters

1. Introduction

The total forest cover, which is equivalent to 67.1% of the territory's surface area [1], is a very heterogeneous set of wood formations, according to Aubreville's classification [2]. These include riparian ecosystems associated with a wet microclimate induced by the presence of a watercourse. In general, in the absence of any anthropogenic action, those ecosystems can take the form of an evergreen dense rainforest or a semi-deciduous dense forest. The characteristic species are also those of a dense humid forest or a secondary forest depending on the age of the stand [3]. The exploitation of gallery forest data reveals that mesophilic and tropophilic types are the least studied, and the Djoumouna forest is an example. Due to their pauciflore and low economic yield, these forests are of less interest despite their inherent fragility in soil and climate conditions [4-6]. This indifference is all the more dramatic when these forests are intra- and/or peri-urban.

Although the disappearance of these natural woody formations has sometimes been compensated by subsidized so-called artificial and generally monoclonal systems, the loss associated with the different levels of biodiversity (α, β, γ) is most often irreversible [7-9]. It cannot even be estimated since no data were collected before their conversion [7-9].

Notwithstanding the direct and indirect benefits (ecosystem goods and services) derived from these ecosystems in urban areas, these woody formations are almost systematically subject to extreme anthropization. The consequences of this irrational management have led, in the urban area of Brazzaville, to the disappearance of the woody formations of La Glacière, Tsiémé, Chad ravine and Corniche, while the forest of Patte d'Oie is reduced to less than 10% of its original cover evaluated at 240 ha, in the Brazzaville region [7-10]. Located on the outskirts of Brazzaville, the Djoumouna forest, which once covered more or less 8 ha, has suffered a loss of almost 50% and is now limited to the private domain of the Scouts and Guides of Congo [11-12].

Cities around the world are sources of heat islands and Brazzaville is no exception [13-15]. While it is well known that the mitigation of the urban heat island phenomenon requires the development of urban and peri-urban woody cover, it is very difficult to estimate the benefits that people gain from exploiting associated ecosystem goods incomes and services [16-20].

This study, which highlights the flora of Djoumouna, aims to improve knowledge of urban and peri-urban woodland ecosystems in order to take better account of them in urban development.

2. Materials and Methods

2.1. Study Environment

With an area of 4.5 ha, the gallery forest of Djoumouna (-04°35' to -04°22' S and 15°15' to 15°09' E) develops about 24 km southwest of Brazzaville, in the Goma Tsé-Tsé sub-prefecture. This area was estimated at 8.5 ha in 1998. Under anthropogenic action, this area is reduced to about 4.5 ha, a decrease of 49% in 19 years [11]. The hydrography is centered around the Djoumouna River, a small permanent tributary of the Congo River, whose source is about fifteen kilometers upstream, in Koubola. This forest is bordered to the north and west by the Nganga Lingolo-Linzolo road, to the south by the Djoumouna river and to the east by the Maloto river (Figure 1).

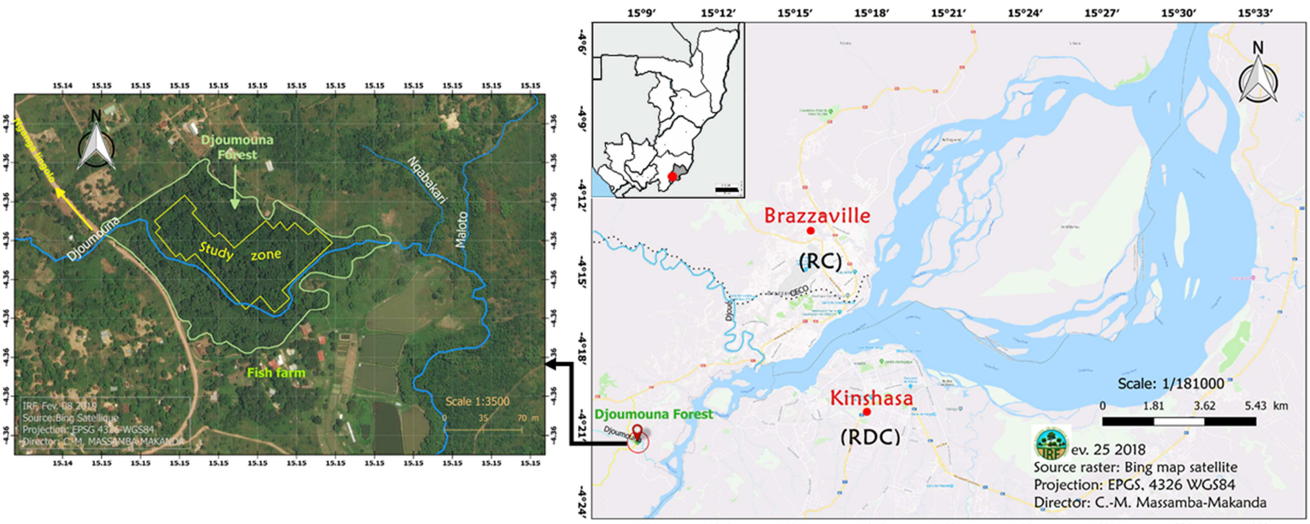

Figure 1. Location of the study area (Source: Google earth processed on Qgis).

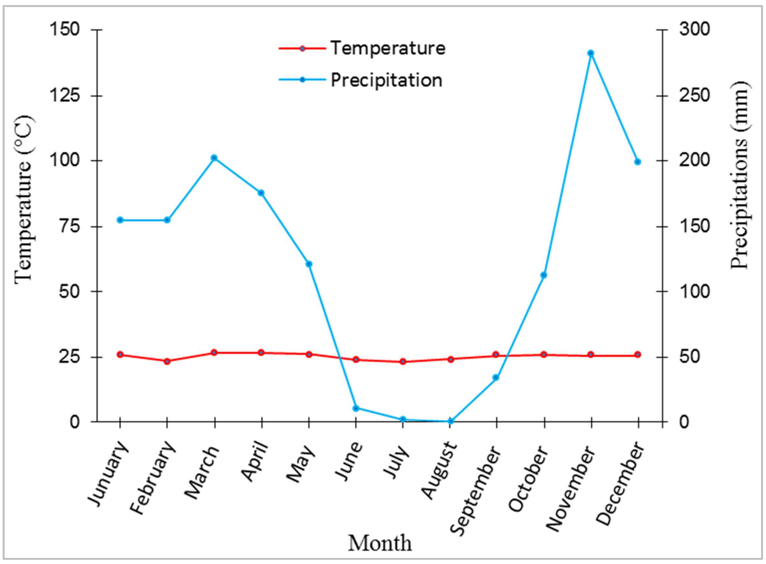

Figure 2. Ombrothermal diagram of Brazzaville during 2000-2016 period (source: ANAC, 2017).

2.2. Climatological Parameters

2.2.1. Temperatures and Precipitation

The climate of Brazzaville and surroundings is Sudano-Guinean, described as low-Congolese [21-22]. It is characterized by: relatively high temperatures with an annual average temperature fluctuating around 25°C with a low thermal amplitude, varying between 4 and 6°C (Figure 2). The warmest period covers March and April, the coolest period is July and August [22-23].

Annual precipitation ranges from 1200 to 1400 mm and is subject to wide variations from year to year [23]. Rainfall begins very lightly at the end of September and extends from October to May, with a very pronounced decrease from January to February. The most watered months are March, April and November with an average of 2000 mm. The months of June, July, August and September are dry (Figure 2). The bimodal precipitation rate induces an alternation between the rainy and dry seasons. The rainy season, the longest, lasts from October to May and is characterized by high temperatures and very high humidity. The dry season lasts 3 to 4 months and is marked by mild (cool) temperatures and no precipitation.

2.2.2. Relative Humidity and Evaporation

Humidity is always high and the annual humidity amplitude is low (Figure 3). However, in the dry season, it remains high and plays an important role for the vegetation. It presents an annual minimum at the end of the season. During the course of a day, relative humidity, unless accidental disturbances due to a thunderstorm, reaches approximately a maximum when the temperature is at its lowest in the early afternoon. The average daily humidity amplitude varies around 33% in the rainy season and 46% in the dry season [22-23].

Evaporation varies in the opposite direction of atmospheric humidity (Figure 3). Data collected at the Maya-Maya weather station show that evaporation has a relative minimum in June and an absolute maximum in August and September [23].

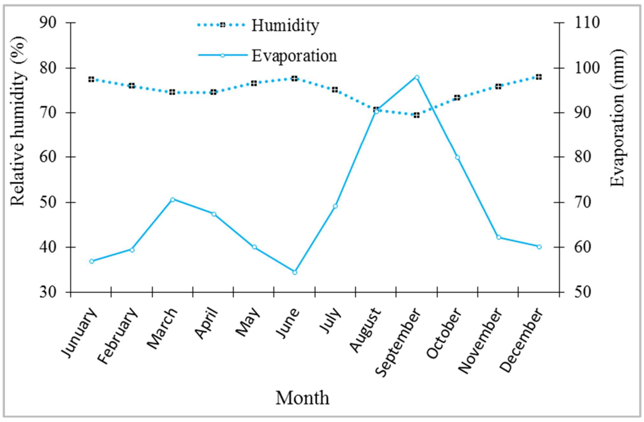

Figure 3. *Brazzaville relative humidity and evaporation during 2000-2016 period (source: ANAC, 2017).*

2.2.3. Insolation

The monthly averages of insolation for the period 2000-2016 (Figure 4) show that it is highest during the months of March and April (181 and 182 Kwh/m^2) and lowest in June (133.9 Kwh/m^2). The annual average is between 1100 and 1800 hours [10, 24].

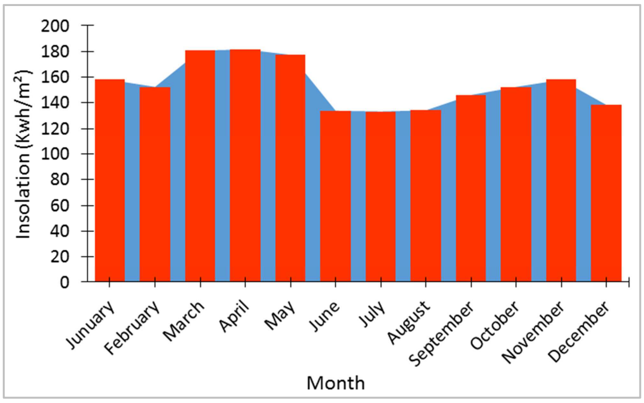

Figure 4. *Insolation of Brazzaville during 2000-2016 period (source: ANAC, 2017).*

2.2.4. Winds

Winds are generally light and dominant in sectors W, WSW and W, with average speed varying between 1 and 3 m/s. At the end of the dry season, winds activity is a little sustained and accentuates the decrease in relative humidity. In the rainy season, north-southeast winds are strong and short-lived, with thunderstorms [10, 24].

2.2.5. Basement and Ground

The geological substratum is mainly sedimentary formations of the Upper Precambrian. From schisto-sandstone nature, it forms the Inkisi series composed of arkoses and feldspars. According to [25-27], this powerful sandstone series (700-800 m) is presented in 2 floors, as follows: *(i)* A lower level (I1) with mainly white mica arkoses, light wine to reddish brown. These formations are quartzite, coarse, intertwined and contain many flat pebbles (quartz, psammitic sandstones, clays) distributed in no order or in lenticular beds. They are particularly clear in the Djoué valley; *(ii)* a higher level (I2) which is essentially composed of siliceous, feldspatic or micaceous sandstones, with rare interspersed argillite. The colour varies from wine lees to brick red; the grain, fine to medium in general, grows towards the base which has a marked arkotic facies.

According to [28], soils belong to the class of highly desaturated yellow reworked ferrallitic soils. Hydromorphic soils are present along the edge of the bed of Djoumouna and its tributaries. Ferrallitic soils have a level I, known as covering, generally thick, then a level II gravel, composed of coarse elements, often indigenous (gravel and pebbles of quartz sandstone for example), finally a level III, known as alteration, mauve to wine bed, very quartzose with many white anastomosed veins. These soils, derived from predominantly siliceous rocks, lack a sufficient humus complex, resulting in very low nutrient fixation. These physico-chemical characteristics coupled with the acidic pH of the said soils make them naturally poor.

Hydromorphic soils have characteristics due to an evolution dominated by the effect of excess water, following temporary or permanent clogging, depth or ensemble caused by the presence or rise of a water table.

2.3. Biological Material Processing and Taxonomic Data

Biological material consists of woody trees and vines with a diameter at chest height (dbh) of 10 cm or more. During this inventory, a herbarium of about twenty species was created and deposited at the national herbarium (IEC) in Brazzaville. Species identification was done in situ for the most common and ex situ, at the National Herbarium (IEC) by comparison and analysis of the diagnoses. The identification material consists of the volumes of flora from Gabon, Cameroon and spermaphytes' flora from Belgian Congo - Rwanda - Urundi, from the work of [29]. The classification followed is APG IV [30] and the taxonomic nomenclature adopted agrees with Lebrun & Stork [31].

2.4. Study Method

The study, which took place from April to August 2017, is based on 2 axes: literature review and the floristic inventory. The literature review provided an opportunity to review the current state of knowledge on the theme of sustainable forest management in the Congo Basin in general, and in particular the urban and peri-urban forests of the Congo Basin.

2.4.1. Botanical Inventory

The botanical inventory is based on the census and measurement of all woody individuals of dbh (diameter at breast height) ≥ 10 cm [32]. The covered area is 3 ha, each of which is subdivided into 25 georeferenced plots of 20 m x 20 m (400 m²), for a total of 75 plots (Figure 5).

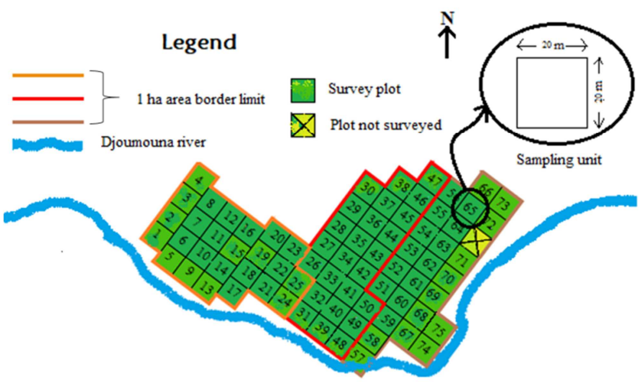

Figure 5. *Sampling design.*

2.4.2. Expression of Results

The results were analyzed according to the most common phytoecological indices.

(1) The raw spectrum

$$SB (\%) = (\text{Number of species per family}) / (\text{Total number of species}) \times 100 \quad (1)$$

(2) The weighted spectrum

$$SP (\%) = (\text{Number of individuals by species or families})/(\text{Total number of species}) \times 100 \quad (2)$$

(3) Jaccard similarity coefficients

$$J (\%) = (C/((A+B)-C)) \times 100 \quad (3)$$

With: A = number of species in survey A; B = number of species in survey B; C = total of species common to A and B

(4) Skewnees coefficient (G)

$$G = \frac{[n.\sum(Xi-\overline{X})]}{[(n-1).(n-2).\delta^3} \quad (4)$$

With N = Number of individuals by species; Xi = dbh of the individual; $\overline{X}$ = Average of the dbh of the sample; δ = type of variation

(5) Shannon Biodiversity Indexes

$$H' = -\sum_{i=1}^{S} pi.\ln pi \quad (5)$$

With: pi = ni/n, ni = number of individuals of species "i"; n = total number of individuals all species combined

(6) Maximum diversity index

$$H'_{max} = Ln(S) \quad (6)$$

With S = total species

(7) Fairness index (regularity or Piélou index)

$$Eq = H'/H'_{max} \quad (7)$$

(8) Alfa-Fisher index (α-Fisher)

$$S = \alpha.Ln (1 + n / \alpha) \quad (8)$$

(9) Effective specific wealth or absolute diversity [61-62].

$$N = e^H \quad (9)$$

(10) Green index (GI)

$$GI = \frac{(\frac{\sigma^2}{\overline{X}}-1)}{N-1} \quad (10)$$

With σ² = Standard deviation of density; $\overline{X}$ = Mean density; N = Total number of species

(11) Species rarefaction index or Géhu and Géhu rarefaction index (1980)

$$Ri = [1 - (ni / N)] \times 100 \quad (11)$$

With: Ri = scarcity index of a species i; ni = number of plots where it is encountered and N = total number of plots inventoried.

Species with a rarefaction index of less than 80% are considered preferential, very frequent and abundant in the areas studied. Those with a rarefaction index of more than 80% are said to be rare and therefore highly threatened with extinction in the locality [60].

(12) Frequency and relative frequency

Frequency = (Number of surveys where the taxon is present)/(Total number of surveys) (12)

(13) Relative frequency (%)

Relative frequency (%) = (Taxon frequency)/(Σ Taxon frequencies) x 100 (13)

(14) Stand density (N in trees/ha)

$$D = N/S \quad (14)$$

With N: total number of trees per plot; S: plot area in ha.

(15) Basal area

$$ST = \sum_{i=0}^{n} \pi r^2 \quad (15)$$

With: r = radius

The basal area, expressed in m².ha^{-1}, indicates the area occupied by the trunk section, projected to the ground.

(16) Hierarchical bottom-up classification (dendrogram) and correspondence factor analysis (AFC) of inventory plot data are processed with XLSTAT software.

3. Results

3.1. Phytodiversity and Taxonomic Data

The overall floristic inventory of the study area reveals 898 tree and vine individuals, authenticating 106 species divided into 83 genera and 36 families. The density of this woody formation is 299.3 trees.ha^{-1}. Floral analysis shows a clear predominance of Fabaceae (22%), followed by Euphorbiaceae (12%), Rubiaceae (8%) and Annonaceae (7%). The smallest families have a contribution ranging from 1 to 5%. The floral composition reveals a woody formation characterized by a high specific diversity and a low floral richness.

3.2. Flora Diversity of Plots

In the plots, the number of families varies from 2 to 11 with an average of 5.84 ± 0.23. The number of trees per family and plot is between 1 and 11. Fabaceae with 276 individuals and an average of 3.68 ± 0.28 tree/plot are dominant with 0 to 10 trees/plot. Euphorbiaceae are 242 trees with an average of 1.89 ± 0.24 tree/plot and a number of individuals per plot between 0 and 11. All other taxa have a number of individuals per plot between 0 and 6, the majority of which are in the range of 0 to 3.

Considering all taxa, the number of individuals per plot ranges from 4 to 21 trees/plot, with an average of 11.97 ± 0.42 trees/plot. Translated into the number of species per plot, there are 3 to 13 species per plot, with an average of 7.37 ± 0.30 species per plot. The overall basal area is 18.57 m².ha^{-1}, while the average is 0.74 ± 0.05 m²/plots.

The raw spectrum of taxa gives values between 5 and 92%, while the weighted range of values varies from 8 to 75% or even 100% in rare cases. The frequency of species ranges from 1 to 45% for an average of 5.23 ± 0.52. The relative frequency of taxa varies from 0.18 to 8.12%.

3.3. Taxa and Spatial Occupancy

Stem counts by species show a clear dominance of very low density taxa (Figure 6). For these species, the density is between 0.33 and 1.67 trees.ha^{-1} with an average of 3 ± 0.71 trees.ha^{-1}. However, it should be noted that 45.28% of this group is dominated by species represented only by 1 or 2 trees. The taxa with a better representativity, in ascending order, are *Hymenocardia ulmoides* Oliv. (16.33 trees.ha^{-1}), *Elaeis guineensis* Jacq. (21.33 trees.ha^{-1}), *Plagiostyles africana* (Müll.Arg.) Prain (22.67 trees.ha^{-1}), *Pentaclethra macrophylla* Benth. (23.67 trees.ha^{-1}), *Pentaclethra eetveldeana* (40.33 trees.ha^{-1}).

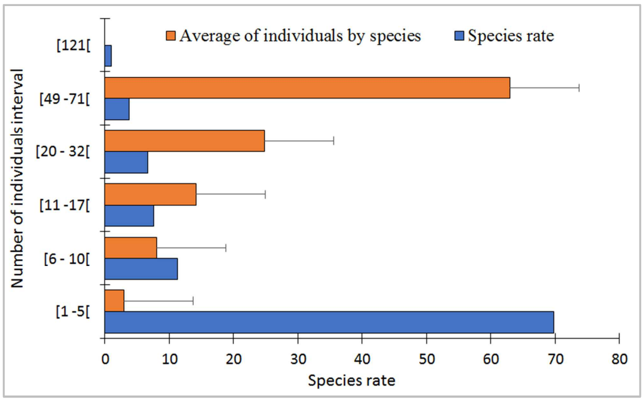

Figure 6. *Synopsis of floristic richness by species.*

3.4. Biodiversity Indices

The Jaccard similarity coefficient among plots is between 0 and 75% with a clear majority of values oscillating from 0 to 57%. The Skewness coefficient oscillates from -2 to 3.61 per plot, with an average of 1.26 ± 0.11. The Shannon diversity index ranges from 0.1 to 2.6 per plot with an average of 1.77 ± 0.05. The maximum diversity varies from 1.1 to 2.6 per plot with an average of 1.93 ± 0.04. The Pielou index varies from 0.6 to 1 per plot, with an average of 0.91 ± 0.01. The absolute diversity index ranges from 2.06 to 13.9 species/plots, with an average of 6.54 ± 0.29. The α-Fisher index ranges from 1.284 to 88.780 with an average of 11.44 ± 1.39. The values of the Green Index range from -0.16 to 0.34 for an average of -0.04 ± 0.01. The species scarcity index reveals 8 frequent and abundant species. These species, which represent 7.55% of the inventory, have a rarefaction index value of between 40 and 77%. However, 98 species representing 92.45% of the total inventory have a rarefaction index ranging from 81 to 99%. These so-called rare taxa are threatened with extinction within this ecosystem

3.5. Bottom-up Hierarchical Grouping of Plots

The aggregation method based on the dissimilarity distance of the Jaccard index by considering the complete link between the floral composition of the plots, discriminates against 9 classes whose components are weakly related (Figure 7). The decomposition of the variance for the optimal intra- and inter-class classification gives 4.993 (85.67%) and 0.835 (14.33%) respectively.

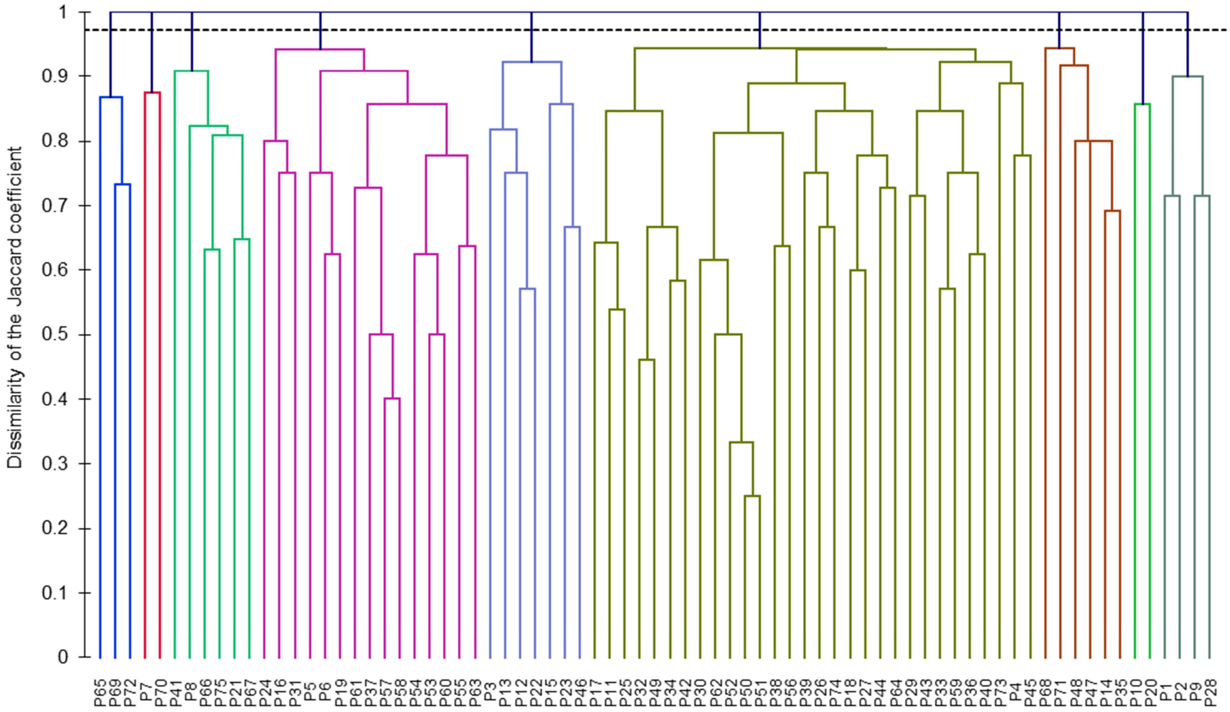

Figure 7. *Upward hierarchical classification of plots.*

3.6. Plot Mapping Factor Analysis

Correspondence factor analysis following the Pearson correlation reveals a dispersion of plots organized around the taxa *Albizia ferruginea*, *Gilbertiodendron dewevrei* and *Microberlinia brazzavillensis* (Figure 8). The total value of the axes is 26.02% and the basic data are shown in Figure 9.

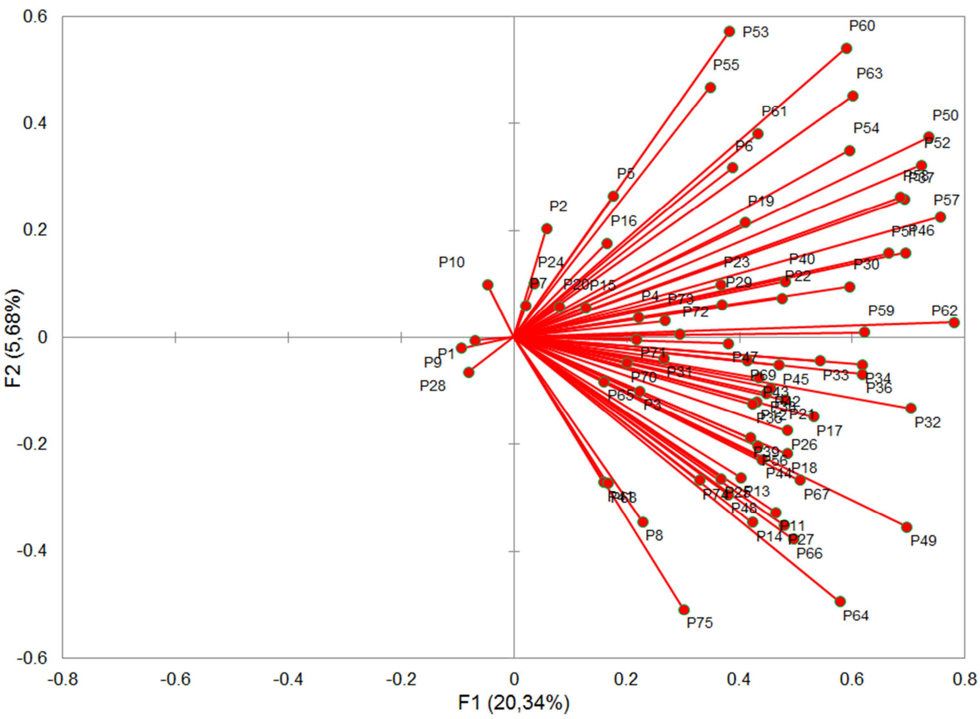

Figure 8. *Mapping factor analysis of floristic inventory units.*

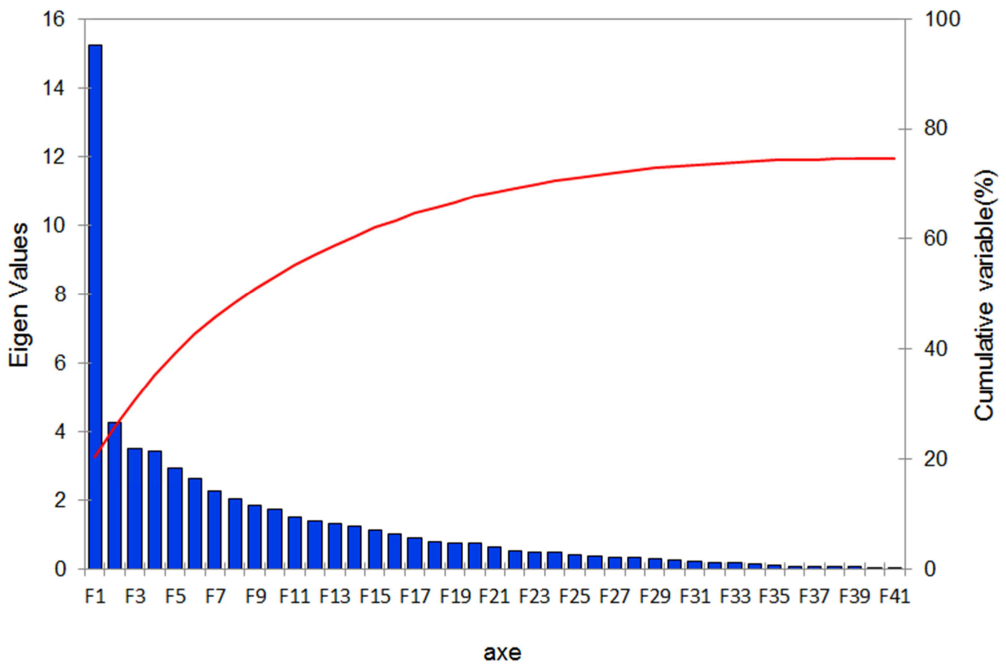

Figure 9. *Basic data of the correspondence factor analysis.*

4. Discussion

4.1. Floral Analysis

Floral diversity, as in all forest formations in the Congo Basin, is dominated by Fabaceae, Euphorbiaceae and Rubiaceae [6, 33, 34]. The floral composition of the Djoumouna forest shows that it is very small compared to the facies of the dense rainforest, where the number of species and trees per hectare is in the hundreds [7, 35, 36, 37, 38, 39, 40, 41].

The Djoumouna forest, which is a link in the dense tropical forests of Central Africa, is characterized by a high degree of specific diversity negatively correlated with floristic richness. Due to its geographical position, this woody formation is mesophilic and tropophilic. Coupled with the high level of anthropization, these parameters alone would control its floristic richness and specific diversity. While these floristic and structural parameters are within known ranges of the Niari Valley homologous forests, they are nevertheless 3 to 5 times lower than the values of the dense humid forests of Central Africa [4, 5, 6, 7, 39, 40, 41, 42, 43, 44]. Despite the low density affecting several of them, the taxa that ensure the floristic affinity of these formations are *Pycnanthus angolensis*, *Staudtia kamerunensis*, *Gilbertiodendron dewevrei, Millettia laurentii, Pentaclethra macrophylla, Pentaclethra eetveldeana, Celtis mildbraedii, Uapaca heudelotii, Crudia laurentii, Canarium schweinfurthii, Santiria trimera, Manilkara aubrevillei, Phyllocosmus africanus, Erythrophleum suaveolens, Blighia welwitschii. Strombosia glaucescense, Strombosiopsis tetrandra, Petersianthus macrocarpus, Klainedoxa gabonensis* [6, 45].

4.2. Analysis of the Bio-ecological Parameters of the Flora

4.2.1. Floral Diversity

The assessment of abundance and dominance, as pointed out by Rollet [46] and Bégué [47], shows that this woody formation does not have typical and representative facies. It is more like a mixed forest where emerging species evolve without gregariousness and clear dominance, as shown by the equity index. As most taxa are rare and threatened with extinction, the distribution and the density of flora are at the origin of the multitude of subfacies observed at the scale of the inventory.

4.2.2. Spatial Distribution and Edaphism of Taxa

The analysis of the floristic composition does not make it possible to define a degree of sociability of taxa at the scale of this formation, and to assign an ecological valence to each species. Species with a high ecological value are those with a rarefaction index of less than 80%. The taxa concerned are *Elaeis guineensis, Hannoa undulata, Hymenocardia ulmoides, Paropsia grewioides, Pentaclethra eetveldeana, Pentaclethra macrophylla, Plagiostyles africana, Psydrax arnoldiana*. Without remarkable gregariousness and dominance, except for *Pentaclethra* sp., these are mainly the species of the dominated strata. From the point of view of spatial distribution, these taxa have no influence, unlike taxa with low ecological valence, whose dispersion model directly influences the floral typology [48]. Most often, it is linked to specific habitat [34, 46, 49, 50, 51, 52, 53]. This group mainly targets emerging species, whose distribution and temperament may explain the problems related to the chorology of the Guinean-Congolese region. Indeed, following the edaphic evolution, pockets of variable extent are observed within this formation [34, 50]. Species that display the distribution pattern in isolated pockets and more or less restricted areas include *Gilbertiodendron dewevrei, Millettia laurentii, Pentaclethra macrophylla, Pentaclethra eetveldeana, Uapaca guineensis, Staudtia kamerunensis*. Therefore, this ecosystem include several subfacies.

The consequences of human action are not only limited to the depletion of plant diversity, but also lead to genetic erosion as a result of changes in ecological niches [54]. In relation to the soil and climate conditions prevailing in the study area, the development of this forest ecosystem would be influenced by soil and non-climatic factors, as Koechlin [24] and Cusset [45] point out. The climatic factors, particularly rainfall, being homogeneous, the confinement of the area of this woody formation results from the nature of the soil and especially the microclimate.

Notwithstanding the degree of anthropization, woody formations in Central Africa frequently exhibit floristic heterogeneity, a corollary of structural complexity, quantitative stability and a high degree of resilience [54, 55, 56, 57, 58, 59, 63]. However, analysis of the floristic composition of the Djoumouna forest reveals that this ecosystem is evolving in the opposite direction to the gains made in tropical forests. Indeed, with 98% of taxa whose density is often less than 1 tree.ha^{-1}, the level of resilience of this formation is very low. These facts highlight insufficient natural regeneration, the result of which is the more or less short-term decline of this forest formation.

5. Conclusion

The peri-urban forest of Djoumouna occupies a cardinal position in the daily satisfaction of goods and services to the community. These direct and indirect needs cover the scope of ecosystem goods and services. Floral data show that this ecosystem is at high risk of extinction due to the combined action of human activities and insufficient natural regeneration. Despite the observed floristic heterogeneity, most taxa have very low densities, which affects the quantity or even quality of seeds necessary for the survival of the species. The floral composition of this woody formation, which does not give well-defined facies, is made up of small subfacies with an area very restricted to a few taxa. Most of the time, facies are very heterogeneous in the floristic composition is divergent even at the plot scale. The result of this spatial distribution of flora coupled with the density of the said taxa is no more or less than the loss of the degree of resilience of this ecosystem.

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