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# Floristic Diversity of the Trees of Street Alignment and Concern of the Populations in Brazzaville

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**Abstract:** The study of the floristic diversity of street trees and the concerns of the population is conducted in Brazzaville. The theme is oriented on the place and the interest of the trees of alignment in the urban development. The methodology is based on the systematic counting of woody trees with a diameter at breast height (dbh) ≥ 10 cm, of 32 arteries selected according to the number of trees in the line and the degree of urban development. The concern of the populations is informed via a questionnaire whose informants are selected following a non-probability sampling for convenience. The floristic inventory lists 1867 woody trees organized into 42 species, 32 genera and 16 families. The allochthonous portion dominates a flora with senescent individuals (*Terminalia mantaly, Millettia laurentii, Pithecellobium dulce, Albizia lebbeck*) and of dbh ≥ 70 cm. Despite a dominance of Fabaceae and Combretaceae, the biodiversity indices reveal a low degree of diversification whose equitability of taxa supports floristic similarity between boroughs. In terms of concerns, while there is unanimity about the ecosystem goods and services derived from avenue trees, the choice of taxa reveals divergences correlated with socio-professional categories. Finally, the poor practice of street trees in urban development gives a negative opinion of this stand with regard to the disservices caused to roads and structures. The roles and functions of the tree being recognized by all, the increase of the woody cover based on local species is desired in order to serve as a reservoir of biodiversity and fulfill the educational action, while underpinning the satisfaction of the daily needs of the populations.

**Keywords:** Avenue Trees, Urban Development, Phytodiversity, Ecosystem Services, Disservices, Biodiversity Index, Brazzaville (Congo)

## 1. Introduction

In Africa, the management and development of cities very often escape the control of political decision-makers, which has worrying repercussions at the socio-ecological level [1]. Urban cities face major challenges in terms of resilience (sustainable development and improvement of the quality of life of citizens), which involves guaranteeing the balance of ecosystems while remaining engines of economic development [2-4]. In urban areas, and everywhere else, the contribution of trees is multiform and is expressed in terms of ecosystem services [5-13]. These services cover several fields such as the guarantee of air quality, carbon sequestration, retention of dust and other impurities, climate regulation, the well-being of populations, the source of food, energy and therapy, mitigation of urban heat islands. From these achievements, the tree provides socio-economic and environmental functions that are gathered under the term ecosystem services [14-20].

In the Congo and particularly in Brazzaville, the demographic explosion of the last decades has induced an exceptional and uncontrolled urbanization. This evolutionary dynamic is leading to the regression of urban vegetation cover. In fact, although the development of the city during the accelerated municipalization process has provided it with physical communication and road infrastructures, this has often been done at the expense of avenue trees and green spaces [21, 22]. Direct disservices to natural ecosystems continues to encroach on the area of urban trees, which are reduced to non-functional spaces that are constantly deteriorating [23]. Notwithstanding the fact that the tree is a formidable natural element of adaptation to climate change and other urban environmental issues, its dimension is poorly perceived in the development policies of Resilient Cities [12, 24]. Without wishing to remind it, the tree generates direct benefits to riparian populations through provisioning services, and indirect ones via regulatory and cultural services whose scope goes far beyond its life range [25-31].

In a context marked by the problems of climate change and sustainable development coupled with the impoverishment of society and the occupation of urban space, the social demand for trees is an ideal response to improve the quality of life in resilient cities [32-37]. Since the 19th century, the tree has become an essential element in urban planning around which concepts such as vegetal urbanism and urban hygiene and even urban ecology have been conceived [6, 7, 19, 38, 39]. Thus, there is a particular focus on ecosystem services and safeguarding biodiversity in urban environments [36, 40-43].

In Brazzaville, the majority of avenue trees are exotic and senescent. Established to provide ecological and landscape functions, avenue trees provide raw materials for handicrafts, herbal medicine and the socioeconomic base of the populations [44]. However, the level of senescence of trees is such that their role in mitigating the effects of climate change, including the ability to sequester more Carbon is low, notwithstanding other ecosystem services. By ensuring more than partially the expected ecological functions, city managers and populations are called to develop sustainable and binding policies for a resilient and attractive environment [22, 32-35, 45]. In a globalized world, the issue of sustainable development is inviting itself at all institutional levels, for a resilient and attractive environment. As a result, the place of the tree and particularly in urban areas is a cardinal element in the design of development policies.

Spatial planning in the context of urban resilience and the well-being of city dwellers is a major concern of municipalities. Its foundation is the improvement of knowledge on the perception of trees by the population and their place in urban planning. Specifically, the study evaluates the perception of residents and users on the social-ecological functions of street trees and assesses the impacts on roadways.

## 2. Material and Method

### *2.1. Presentation of the Study Environment*

Brazzaville, the political and administrative capital of the Republic of Congo, lies between 15.2061 - 15.3175 S, -4.2183 - 4.2992 E (Figure 1). The surface area of Brazzaville is about 32640 hectares (or 32640 km²) of which 1/4 covers a formerly marshy plain and 3/4 of the plateaus and hills, whose altitude barely reaches 300 m [46].

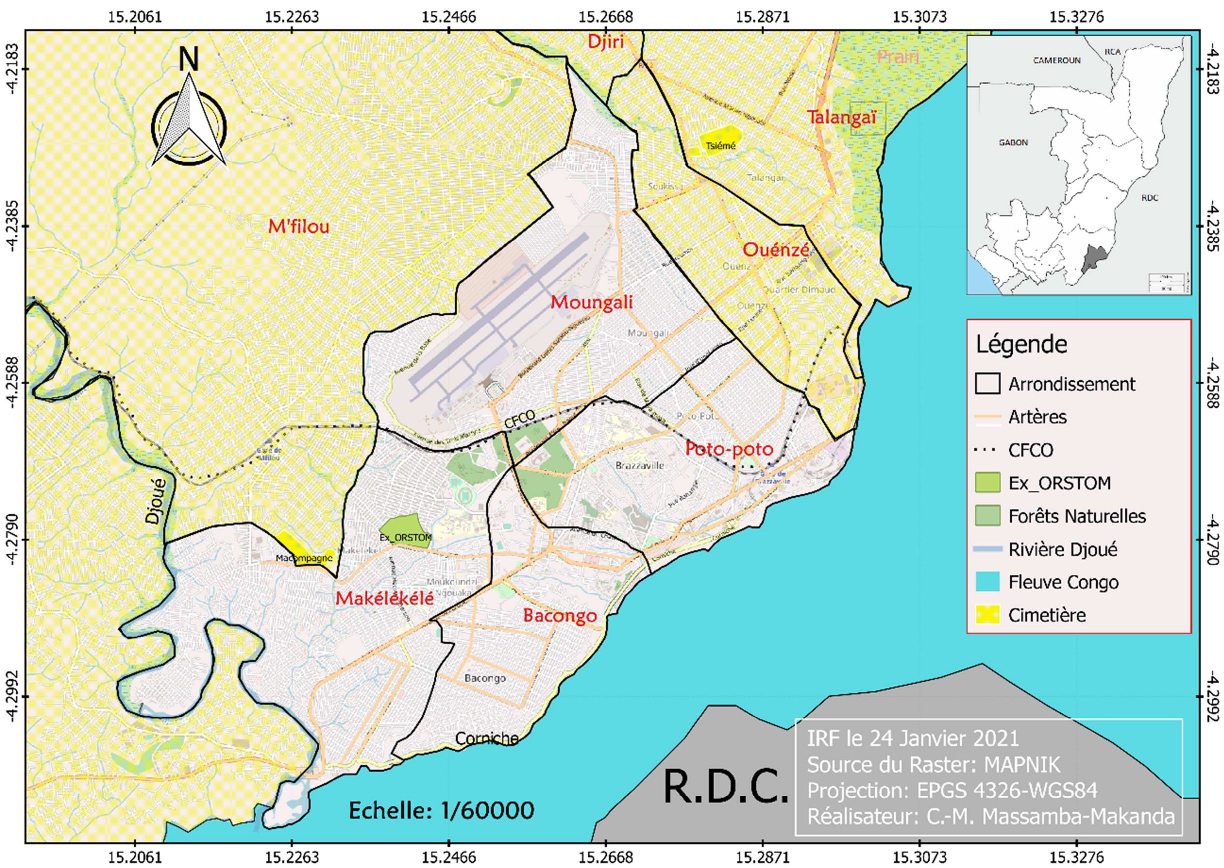



***Figure 1.*** *Geographic location of the study site.*

The climate is AW3 [47-52] characterized by: a cool dry season from June to September; a wet and warm rainy season from October to May, with a pronounced slowdown in January and February [53, 54]. Annual rainfall is about 1400 mm and the average annual temperature is about 25°C with a small thermal amplitude that does not exceed 5-6°C [53, 54]. Heat peaks are observed in the months of March, April and November. Relative humidity is above 70%. An absolute minimum is noted in August and September, a relative minimum in February and March. The minima vary from 50 to 60%, while the maxima are above 80% [46, 55].

### 2.2. Vegetation and Flora of Brazzaville

The Brazzaville region belongs to the Léfini natural region corresponding to the Léfini phytogeographic district [56]. The urban area of Brazzaville currently includes two forest islands resulting from the degradation of the Patte d'Oie forest. Originally, Brazzaville and its surroundings were covered by forests and savannahs characterized by a *Trachypogon thollonii* and *Annona senegalensis* group with two subgroups: *Hyparrhenia diplandra and Bridelia ferruginea* characterize the clay soils; *Loudetia demeusii* and *Hymenocardia acida* the sandy soils [55]. Forests develop on the plateaus in the form of groves of very small area and often of anthropogenic origin. The degraded and secondarized mesophilic forests occupy about 5% of the surface. This forest type is also found in the hilly areas bordering the city, where gallery forests dominate [55].

The urban forest ecosystem is centered on riparian forests and mesophilic and tropophilic patches resulting from the degradation of the Patte d'Oie forest [56-59]. In addition to these natural facies, there are artificial woody formations, mainly of *Corymbia* sp. and *Pinus caribaea*, to which are added:

1) Linear trees, planted in a linear and regular manner along arterial roads, mainly *Acacia mangium, Terminalia superba, Terminalia mantaly, Terminalia catappa, Mangifera indica, Millettia laurentii, Peltophorum pterocarpum*;
2) Yard trees, especially fruit trees, which occupy the empty space next to the buildings: *Mangifera indica, Persea americana, Dacryodes edulis, Carica papaya, Ficus carica, Cocos nucifera, Trilepisium madagascariense, Elaeis guineensis, Spondias dulcis, Hura crepitans, Gardenia ternifolia;*
3) Fence trees that form living hedges limiting private concessions: *Dracaena fragrans, Newbouldia laevis, Quisqualis indica, Clerodendron inerme*.
4) Garden trees (landscaped area planted with trees and shrubs) which are: *Senna siamea, Millettia* sp., *Corymbia* sp., *Pinus caribaea, Lagerstroemia speciosa, Terminalia catappa, Hura crepitans, Albizia lebbeck*.

### 2.3. Material

The material consists of arboreal woody trees of "diameter at breast height (dbh) ≥ 10 cm" present along the arteries for the phytodiversity study. Identification of trees and shrubs is done in situ for common species and ex situ at the National Herbarium (IEC) for the others. The nomenclature adopted is that of Lebrun and Stork [60] and the taxonomic order results from APG IV [61].

Arterial discrimination is based on the number of trees, at least ten aligned individuals of dbh ≥ 10 cm in a 700-meter stretch, roadway and/or structure development. To these very flexible selection criteria, only 32 arteries in four districts (Makélékélé, Bacongo, Poto-poto and Moungali) out of nine met the challenge. It is interesting to note that the selected arteries are distributed in the four oldest districts of the city.

### 2.4. Study Methodology

The literature review made it possible to assess the state of knowledge on topics related to urban and peri-urban forestry in general, and urban arboriculture in Brazzaville in particular. Finally, to refine the development of data collection tools, including survey sheets and interview guides.

#### 2.4.1. Collection of Phytodiversity Data

Systematic enumeration of all alignment trees of dbh ≥ 10 cm in the 32 selected arteries and collection of dendrometric data (dbh, height). Other parameters monitored are the vital space reserved for the tree during development, the spacings separating (i) roadways and alignment trees, and (ii) disservices caused to infrastructure are recorded. Finally, the opinions of residents and users were collected using an open-ended questionnaire.

#### 2.4.2. Group of Informants

A non-random sampling is used for the selection of informants. The survey is of interest to users, residents along the arterial roads, and people working along the wooded arterial roads. In addition, the interviews are of interest to resource persons involved in the management of urban trees. The focus was on their approach or vision of the current state and prospects of urban forestry. Taking gender into account, informants should be at least 15 years old.

### 2.5. Data Processing and Analysis

#### 2.5.1. Biodiversity Parameters

The analysis of qualitative floristic diversity was based on inventory data, without incorporating epiphytes, parasites and hemiparasites present on the said phorophytes. These taxa include orchids, pteridophytes, loranthus, lichens, bryophytes and fungi.

*Ecological Spectra*

*1) The gross spectrum*

The gross spectrum (BS) is the frequency of scoring of plants belonging to different types.

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

*2) The weighted spectrum*

The weighted spectrum (WS) focuses on the floristic biodiversity of each taxon (family). This index allows us to know the degree of coverage of each taxon.

SP (%) = (Number of individuals of species or family)/(Total number of individuals of species or family) x 100

### *2.5.2. Biodiversity Indices*

Species diversity is an essential ecological dimension that can be assessed by:

*1) Effective species richness or absolute diversity (N)*

Species richness is the total number of species in a sample

$$N = e^H$$

*2) Jaccard's similarity coefficients*

Jaccard's similarity coefficient, the most commonly used in ecology, gives the same information value to the presence and absence of species.

Jaccard: S (%) = (C/(A+B)-C) x 100

Where A = number of species present in the first station, B = number of species present in the second station and C = number of species common to both stations.

*3) Shannon Index*

The Shannon index expresses diversity by taking into account the number of species and the abundance of individuals within each species.

$$H' = - \sum_{i=1}^{n} PiLn(Pi)$$

*4) Maximum diversity index*

The maximum floristic diversity provides information on the degree of diversity that a phytocenosis in the case of a homogeneous distribution of the constituent individuals of the flora.

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

With S = total of the species.

*5) Pielou's equitability index*

Pielou's equitability index or regularity index is the ratio of Shannon's diversity index to the theoretical maximum diversity index in the stand [57, 58].

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

*6) Alpha-Fisher diversity index*

The Alpha-Fisher diversity index is insensitive to sampling effort. The Alpha-Fisher diversity index only requires knowledge of the total number of individuals in a plant community and the corresponding number of species.

$$S = \alpha\ln(1+N/\alpha)$$

Where "S" is the species richness and "N" is the number of individuals.

*7) Gehu and Gehu's rarefaction index*

Ri = [1 - (ni/N)] x 100

Where "ni" represents the number of arteries where the species is encountered; "N" represents the total number of arteries inventoried.

Species with a rarefaction index of less than 80% are considered very frequent and abundant in the selected arteries, while those with a rarefaction index of more than 80% are considered rare, vulnerable and endangered in the locality.

*8) Absolute frequency*

Frequency = (Number of arteries where the taxon is present)/(Total number of arteries) X 100

*9) Relative frequency*

Relative frequency = (Frequency of taxon)/(Σ frequencies of taxa)× 100

### *2.5.3. Structural Parameters*

*Diametric structure*

Diameter structure indicates the number of stems inventoried by diameter class. The persistence of a species in the forest community depends largely on its representation in the different diameter classes [62].

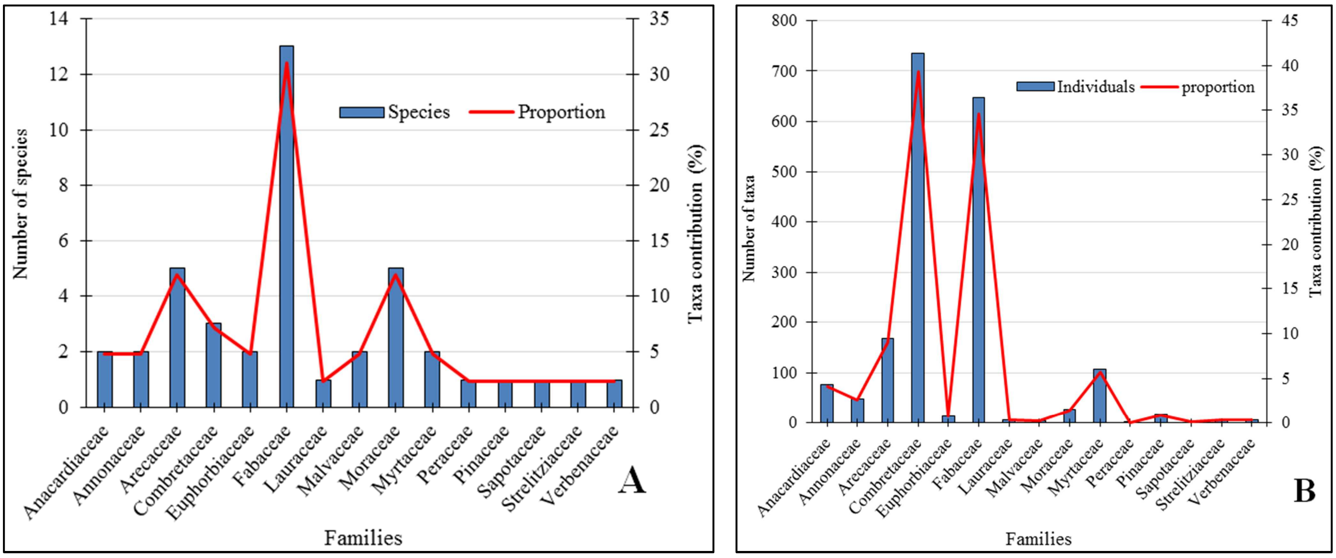
## 3. Results

### *3.1. Phytodiversity Data*

The inventory of the woody flora of the 32 sections of arteries in the city of Brazzaville reveals 1867 individuals of dbh ≥ 10 cm corresponding to 15 families, 31 genera and 42 species (Table 2). The specific contribution singled out Fabaceae (30.95%), Arecaeae and Moraceae, with 11.90% of the taxa (Figure 2A). However, the best floristic contributions, at least 100 individuals, highlight the Combretaceae (39.37%), Fabaceae (34.35%), Arecaceae (9.05%) and Myrtaceae (5.73%) (Figure 2B). The analysis of the floristic composition shows ratios of 1/3 local species and 2/3 non-native species. The coverage of avenue trees, although evident, differs from one district to another. These differences would explain the level of development that each district benefits from. Apart from Moungali, which cannot be compared to the other three, the differences in the number of individuals are on average twice as great. However, the analysis of specific diversity reveals very marked differences between the districts (Table 3).

### *3.2. Diameter Structure of Stands*

Within the stands of Brazzaville, the diametric structure of the woody plants shows significant variations in the number of individuals according to the diameter classes. Diameter classes 2 and 3 are better represented in the arteries studied (Figure 3). The overall distribution shows an irregular (erratic) decreasing trend. The evolution of individuals from small to large diameter classes is irregular. The artificial feature of the system could explain this observation, which is under anthropic control. This observation suggests more than one source of explanation, notably the lack of maintenance of avenue trees, anthropic mutilations that cause standing dead and malformed trunks.




Legend: brut (A) and Weighted (B)

***Figure 2.*** *Floristic spectrum of street trees in Brazzaville.*

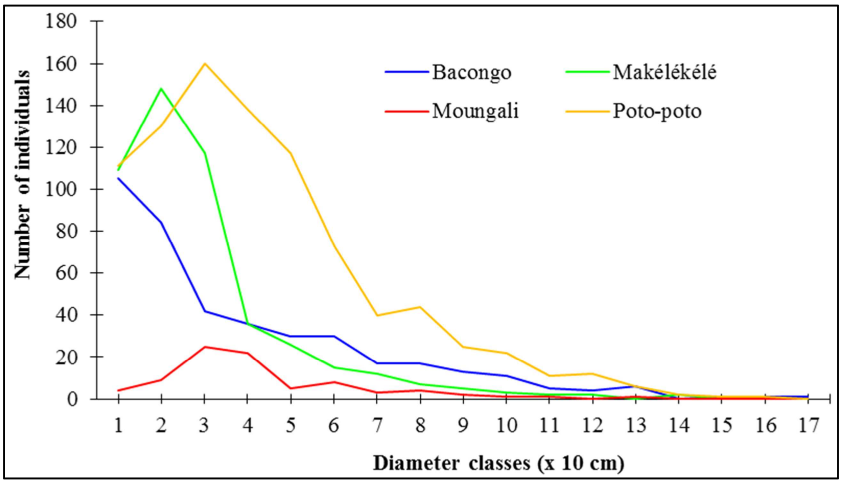



***Figure 3.*** *Evolution of the diametric structure of avenue woody plants.*

### *3.3. Biodiversity Index Data*

#### *3.3.1. Coefficient of Similarity*

Jaccard's similarity coefficient reveals a very low degree of homogeneity in the floristic composition of Brazzaville's arteries (Table 1). This index indicates a clearly different floristic composition between (i) the arteries and (ii) the districts. Except for Poto-Poto and Bacongo where the similarity coefficient is at least 59%, all other rates oscillate in the range of 16 to 41%. Moungali is the district that stands out the most from the others.

#### *3.3.2. Rarefaction Index of Géhu and Géhu*

The rarefaction index reveals 15 species (36.58%) frequently present in the inventoried arteries (Figure 4). However, 27 species have a high rarity index, placing them in the classes of rare or very rare taxa. These taxa, which constitute the majority of the inventory (63.41%), would be qualified as vulnerable or threatened with extinction (Figure 5). This data should be qualified, however, for taxa of recent or accidental introduction in alignment. This non-exhaustive cohort is composed of *Polyalthia longiflora, Cananga odorata, Pentaclethra macrophylla, Manilkara zapota, Ricinodendron heudelotii*. Finally, the decline of the taxa known for a long time as street trees would be attributable to a deficiency of maintenance. The plausibility of the event would be the anthropic character that affects almost all the ecological parameters of this stand.

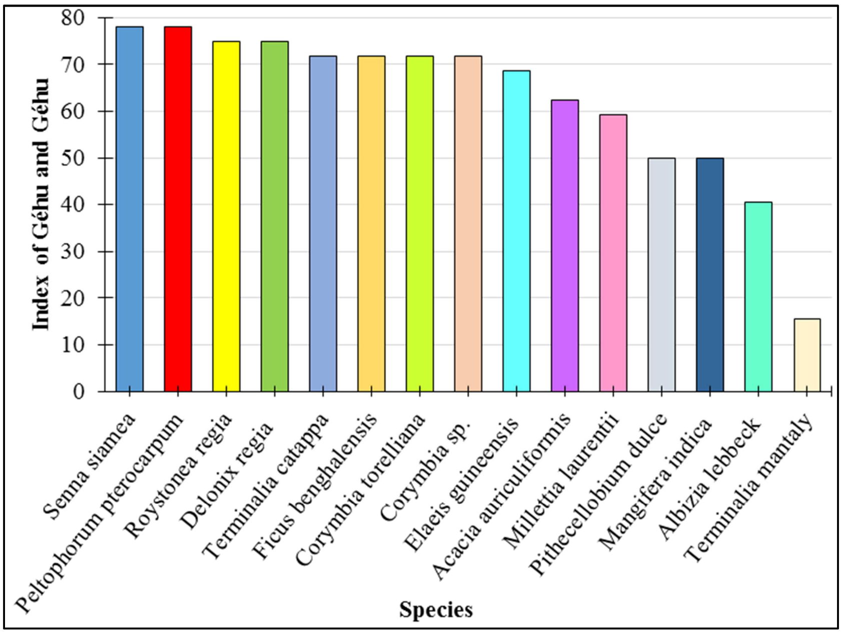



***Figure 4.*** *Common species in street rows.*

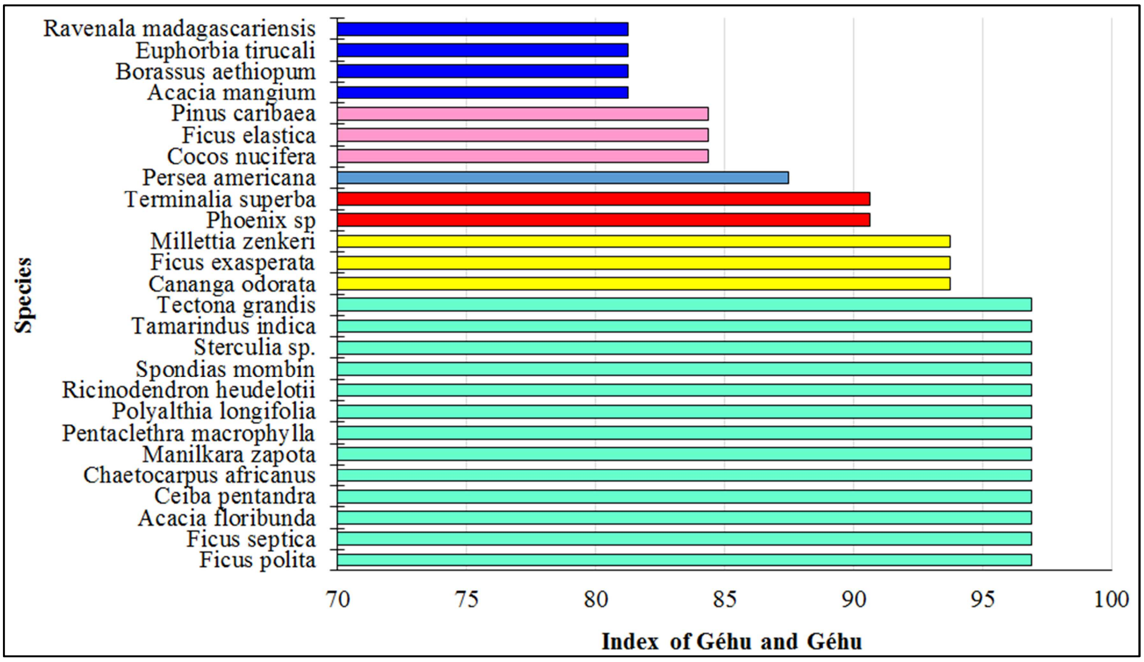



***Figure 5.*** *Synopsis of rare taxa found in alignment.*

### *3.3.3. Indices of Biological Diversity*

The indices of biological diversity reveal a very low degree of diversification in general and varying from one district to another (Table 2). The subtlety of floristic homogeneity is thought to be the source of the insidious trend of underlying gregariousness in Makélékélé and Moungali.

***Table 1.*** *Overview of biodiversity index data.*

| Indexes | Bacongo | Makélékélé | Moungali | Poto-poto | Mean |
|---|---|---|---|---|---|
| Shannon (H') | 2.85 | 1.36 | 1.35 | 2.63 | 2.05 ± 0.40 |
| $H'_{max}$ | 6 | 6.18 | 4.44 | 6.79 | 5.85 ± 0.50 |
| Equitability (J) | 0.81 | 0.5 | 0.69 | 0.76 | 0.69 ± 0.07 |
| Alpha-Fisher | 8.50 | 2.93 | 1.81 | 6.49 | 4.93 ± 1.55 |
| Absolute diversity | 17.29 | 3.9 | 3.86 | 13.87 | 9.73 ± 3.45 |

***Table 2.** Floristic richness and distribution of woody plants.*

| Taxa | Bacongo | Makélékélé | Moungali | Poto-poto | Total |
|---|---|---|---|---|---|
| Anacardiaceae | 7 | 8 | - | 61 | 76 |
| *Mangifera indica* L.* | 5 | 8 | - | 61 | 74 |
| *Spondias mombin* L.* | 2 | - | - | - | 2 |
| Annonaceae | - | - | - | 48 | 48 |
| *Cananga odorata* (Lam.) Hook F. & Thomson* | - | - | - | 44 | 44 |
| *Polyalthia longifolia* (Sonn.) Thwaites* | - | - | - | 5 | 5 |
| Arecaceae | 31 | 3 | 37 | 98 | 169 |
| *Borassus aethiopum* Mart. | - | - | 1 | 5 | 6 |
| *Cocos nucifera* L.* | 6 | - | - | 43 | 49 |
| *Elaeis guineensis* Jacq. | 8 | 3 | - | 32 | 43 |
| *Phoenix* sp. | 3 | - | 1 | - | 4 |
| *Roystonea regia* (Kunth) O. F. Cook* | 14 | - | 35 | 18 | 67 |
| Combretaceae | 92 | 333 | 18 | 292 | 735 |
| *Terminalia catappa* L.* | 5 | 9 | - | 34 | 48 |
| *Terminalia mantaly* H. Perrier* | 75 | 324 | 17 | 257 | 673 |
| *Terminalia superba* Engl. & Diels | 12 | - | 1 | 1 | 14 |
| Euphorbiaceae | 9 | 4 | - | 1 | 14 |
| *Euphorbia tirucalli* L. | 9 | 4 | - | - | 13 |
| *Ricinodendron heudelotii* (Baill.) Pierre ex Heckel | - | - | - | 1 | 1 |
| Fabaceae | 203 | 128 | 30 | 285 | 647 |
| *Acacia auriculiformis* A. Cunn. ex Benth.* | 17 | 12 | - | 25 | 54 |
| *Acacia floribunda* (Vent.) Willd.* | 21 | - | - | - | 21 |
| *Acacia mangium* Willd.* | 8 | 14 | - | 3 | 25 |
| *Albizia lebbeck* (L.) Benth.* | 12 | 20 | 4 | 68 | 104 |
| *Delonix regia* (Bojer) Rafin* | 5 | 4 | | 7 | 16 |
| *Millettia laurentii* De Wild. | 59 | 34 | 26 | 66 | 185 |
| *Millettia mannii* Baker | 5 | 3 | | - | 8 |
| *Pentaclethra macrophylla* Benth. | 1 | - | - | - | 1 |
| *Peltophorum pterocarpum* (DC.) Backer ex K. Heyne* | 15 | - | - | 63 | 78 |
| *Pithecellobium dulce* (Roxb.) Benth.* | 57 | 41 | - | 26 | 124 |
| *Senna siamea* (DC.) Irwin & Barneby* | 3 | - | - | 26 | 29 |
| *Tamarindus indica* L.* | - | - | - | 1 | 1 |
| Lauraceae | 1 | 2 | - | 3 | 6 |
| *Persea americana* Mill.* | 1 | 2 | - | 3 | 6 |
| Malvaceae | 3 | - | - | 2 | 5 |
| *Ceiba pentandra* (L.) Gaertn.* | 1 | - | - | 2 | 3 |
| *Sterculia* sp.* | 2 | - | - | - | 2 |
| Moraceae | 14 | 1 | - | 12 | 27 |
| *Ficus benghalensis* L.* | 7 | - | - | 5 | 12 |
| *Ficus elastica* Roxb. ex Hornem.* | 5 | - | - | 2 | 7 |
| *Ficus exasperata* Vahl | 2 | - | - | 4 | 6 |
| *Ficus polita* Vahl | - | - | - | 1 | 1 |
| *Ficus septica* Burm.f. | - | 1 | - | - | 1 |
| Myrtaceae | 26 | 5 | - | 76 | 107 |
| *Corymbia* sp.* | 22 | 5 | | 32 | 59 |
| *Corymbia torelliana* (F. Muell.) K. D. Hill & L. A. S. Johnson* | 4 | - | - | 44 | 48 |
| Peraceae | 1 | - | - | - | 1 |
| *Chaetocarpus africanus* Pax | 1 | - | - | - | 1 |
| Pinaceae | 5 | - | - | 12 | 17 |
| *Pinus caribaea* Morelet* | 5 | - | - | 12 | 17 |
| Sapotaceae | 3 | - | - | - | 3 |
| *Manilkara* sp. | 3 | - | - | - | 3 |
| Strelitziaceae | 4 | - | - | 2 | 6 |
| *Ravenala madagascariensis* Sonn.* | 4 | - | - | 2 | 6 |
| Verbenaceae | 6 | - | - | - | 6 |
| *Tectona grandis* L. F.* | 6 | - | - | - | 6 |
| Total | 405 | 484 | 85 | 893 | 1867 |

(*) Naturalized and non-native taxa

### 3.4. Tree Perception Data

#### 3.4.1. Informant Group

The group of informants consisted of 231 people of all genders. In addition to gender, the survey took into account age, marital status, socio-professional qualification and level of education (Table 3). The heterogeneity of the composition of the group of informants is a fundamental asset for a good coverage of the study area.

***Table 3.*** *Profile of the informant group.*

| Characteristics | | Number of citations | Frequency of citation (%) |
|---|---|---|---|
| Genre | Men | 125 | 54.11 |
| | Women | 106 | 45.89 |
| Age groups | 15 - 25 years old | 20 | 8.66 |
| | 25 - 35 years old | 57 | 24.68 |
| | 35 - 45 years old | 74 | 32.03 |
| | Over 45 years old | 80 | 34.63 |
| Marital status | Single | 128 | 55.41 |
| | Married | 86 | 37.23 |
| | Widowed | 4 | 1.73 |
| | Divorced | 20 | 8.66 |
| Qualification | Retired | 5 | 2.16 |
| | Unemployed | 12 | 5.19 |
| | Worker | 4 | 1.73 |
| | Farmer | 5 | 2.16 |
| | Shopkeeper | 42 | 18.18 |
| | Craftsman | 7 | 3.03 |
| | Trainee | 30 | 12.99 |
| | Civil servant | 74 | 32.03 |
| | Employee | 54 | 23.38 |
| Level of education | Primary | 8 | 3.46 |
| | Secondary | 71 | 30.74 |
| | Higher | 141 | 61.04 |
| | Unschooled | 11 | 4.76 |

### *3.4.2. Perception of Avenue Trees and Society*

The duality between the perception of the avenue tree and society puts more emphasis on regulatory services in general (Table 4). A closer look at the survey data reveals that society's perception of the avenue tree is a function of the informant's social position. Indeed, the appreciation of each individual is most often dependent on the expected benefits. This finding is due to two main reasons: the majority of the cohort is non-fruit bearing and dominated by non-native taxa. In terms of the frequency of quotations and without distinguishing between levels of education, the involvement of men is very clear, with rates of over 50% of informants.

In addition, the level of knowledge of the environmental role of lineage trees evolves in proportion to the level of education (from primary to secondary to higher education). The level of education would allow us to sort out and refine the subtlety of the informants' real perception of ecosystem services and disservices. These functions interest more than 40% of the respondents and cover more than one ecosystem service. Among the informants, 61.50% admit the impact of street trees on the urban microclimate. However, the other functions have low frequencies of quotations ranging from 0.83 to 5.09% for a male participation oscillating from 42.86 to 70.59% and a female participation ranging from 29.41 to 57.14%.

***Table 4.*** *Perception of ecosystem services by gender.*

| Perception | Ecosystem services | Frequency of citations (%) | Men (%) | Women (%) |
|---|---|---|---|---|
| Overall | shading | 11.06 | 56.50 | 43.50 |
| | air quality | 8.74 | 54.43 | 45.57 |
| | power supply | 6.97 | 57.94 | 42.06 |
| | aesthetics | 6.80 | 53.66 | 46.34 |
| | air pollution control (retention of dust, ashes, and other substances) | 6.47 | 55.56 | 44.44 |
| | erosion | 6.03 | 56.88 | 43.12 |
| Level of education | windbreak | 5.81 | 60.00 | 40.00 |
| | recreational area | 5.09 | 58.70 | 41.30 |
| | raw material for crafts | 4.37 | 58.23 | 41.77 |
| | source of inspiration | 4.31 | 60.26 | 39.74 |
| | open-air workshop for small crafts | 4.09 | 62.16 | 37.94 |
| | rainwater interception | 3.21 | 62.07 | 37.93 |
| | air pollution control | 3.01 | 66.07 | 33.93 |
| | urban eco-tourism | 2.93 | 64.15 | 35.85 |
| | noise reduction | 1.94 | 42.86 | 57.14 |
| | therapeutic source | 1.88 | 70.59 | 29.41 |
| | psychological effects | 1.11 | 60.00 | 40.00 |
| | water infiltration | 0.83 | 66.67 | 33.33 |

### *3.4.3. Perception of the Vegetation Cover and Floristic Composition*

The assessment of the evolution of the vegetation cover makes it possible to evaluate the efforts made in recent years in the fight against global climate change through the planting of trees. The data collected are very mixed and reflect the perception of the population from one neighborhood to another. The perception of the population depends on social categories (socio-professional, marital status and level of education). A detailed analysis of the data collected, according to gender, reveals a strong involvement of women in environmental issues (Figure 6). This female participation is associated with the impoverishment of the society, whose members' energy and financial needs are dependent on the ecosystem services, particularly the supply of trees. The study shows that 22.52% of the informants affirmed the regression of the number of trees in the forest. On the other hand, 4.35% consider the paving of arteries to be sufficient. 15.36% of the respondents speculate on the senescence of the trees of alignment; while a minor fringe of 3.77% find them juvenile. According to the needs and social situation of the informants, the dreamed floristic composition reflects more than one expectation. In fact, 8.12% want ornamental trees to be introduced in an alignment; 7.34% prefer fruit trees; 2.42% advocate medicinal plants; and finally, 5.89% of respondents advocate shade-providing plants. From the different opinions, the general result reveals a mixed appreciation of street trees. While recognizing the place of avenue trees in urban planning, expectations are diverse and guided by interests related to individual satisfaction, hence the difficult choice of the appropriate taxon.

A consensus emerged among the group of informants on the future of avenue trees. The unifying parameters are monitoring, maintenance, replacement and increasing the vegetation cover. About 48.60% of the respondents advocate the replacement of senescent flora by juvenile subjects; 47.90% advise to maintain and care for the existing. Finally, in view of the disservices on structures and roads, a minority of respondents (2.57%) suggested razing everything and replanting it, respecting the minimum requirements for trees in line. Thus, 7.34% of the informants express the wish to privilege local flora. Notwithstanding the danger and disservices caused to roads, people and their property, which accentuate a negative perception of street trees, the actors agree on the cardinal values of urban arboriculture. Among other values, let's list the conservation and the valorization of the local flora, the taking into account of the ecosystem services, notably of regulation.

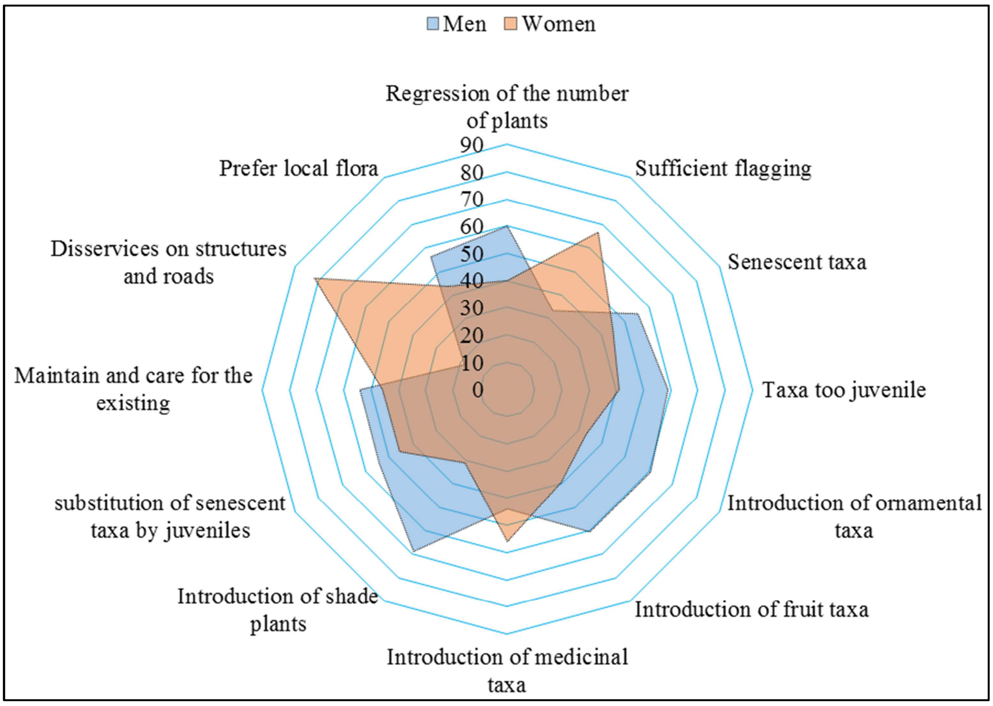



***Figure 6.*** *Perception of alignment plants by gender.*

### *3.4.4. Benefits Resulting from the Exploitation of Avenue Trees*

Linear trees are the basis of a pecuniary and artisanal activity, supporting it directly or indirectly (Figure 7). Following a decreasing order of frequency of quotation of activities, 11.53% of respondents authenticate an exploitation for artisanal purposes. The manufacture of benches was cited by 6.15% of respondents; 10.70% found a source of wood energy; 9.82% collected bark for various reasons and specifically 7.45% used it as a basis for traditional pharmacopoeia. Finally, for the same reason related to the satisfaction of health care, 8.93% exploit the roots of the said trees; in an exceptional way, 5.62% cite the food use of taxa such as *Mangifera indica, Persea americana, Tamarindus* *indica, Elaeis guineensis, Cocos nucifera, Spondias mombim*. Concomitantly to the exploitation of the different organs and notwithstanding the motive, 90.48% of the respondents certify that the avenue trees contribute to the formation of the families' income. Avenue trees are providers of ecosystem goods and services. In addition to the provisioning services that anyone can claim, the interest of the craft overrides any value by sequestering carbon for a very long time. Thus, through these mechanisms, the City integrates the notion of fighting against the effects of climate change.

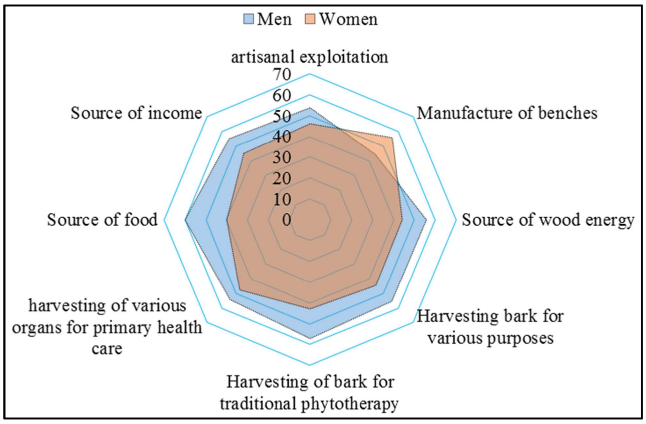



***Figure 7.*** *Value added by the population from alignment plants.*

In addition to the tangible aspects, the informants emphasized the intangible benefits that affect the daily lives of local residents. At 15.86%, shading was cited as a way to reduce air conditioning costs. On the other hand, 13.9% of respondents emphasize that trees contribute to the reduction of costs induced by runoff. Finally, the increase in real estate value is noted by 12.64% of informants.

### *3.4.5. Street Trees and Spatial Planning*

Urban trees in general and street trees in particular, while conveying the virtues of well-being to the population and resilience to the city, are also vectors of disservices to roads, people and their property.

### *3.4.6. Disservices Caused by Urban Trees*

Urban trees cause disservices and generate unforeseen financial costs to the City's budgets (Figure 8). Among other disservices, we note the cracking and destruction of urban structures such as gutters and pavements, for which the frequency of citation is 26.74%. The obstruction of communication arteries and artificial outlets is 7.09%. The destruction of water supply, electricity and telephone networks is cited by 13.40% of informants. The insalubrity due to the fall of leaves and fruits for 10.88%. The loss of human life caused by traffic accidents was cited by 10.46% of respondents, with traffic accidents accounting for 9.68%. Finally, the urban banditry, in terms of hiding place of the aggressors, quoted at 8.98%. Lastly, the informants (7.84%) underlined the allergenic trait of certain organs produced by the alignment plants. The trees of avenues are a source of pollution and inconvenience, once the installation is not in conformity with the decreed norms. Thus, additional costs are requested to treat the induced effects, at the level of the City.

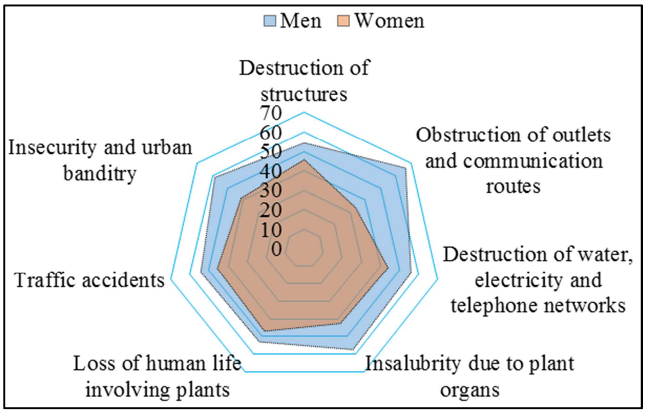



***Figure 8.*** *Perceived disservices to street trees.*

## 4. Discussion

### *4.1. Analysis of the Floristic Diversity of Street Trees*

The history of street trees in Brazzaville dates back to the 1880s and coincides with the creation of the City, as confirmed by IGN (ex CERGEC) archives [63]. The first taxa introduced in alignment along the arterial roadsides are *Ananas comosus* and *Psidium guayava*. The choice of these neotropical taxa could be explained by (i) the imperatives of conservation and propagation, knowing that the city has developed in a savannah and swampy zone; (ii) or simply a question of maintaining the original spatial aesthetics [63, 64]. This trend, which persists to this day, is the result of (i) transcontinental exchanges, the consequence of which is the extension of the ranges of several taxa, and (ii) the lack of data on the topic, in order to enhance the local flora [63-66]. The floristic diversity of avenue trees in Brazzaville emphasizes exotic flora to the detriment of local flora, as is the case in more than one Sub-Saharan urban city [63, 66]. The reason for this dominance is to be found in (i) the history of human transhumance from the colonial era and regional speculation, (ii) and, the almost non-existent exploration of the local flora in order to select interesting taxa for this purpose [63-66]. This consideration biases people's expectations of the conservation functions of local taxa at the urban forestry level. Thus, the educational and aesthetic values of local flora are obscured. However, the stigma of collecting bark samples from individuals, avenue trees, testifies to the integration of the said taxa into the foundation of local knowledge [67]. Well managed, these plants come at the right time to enrich the flora of the region and, in fine, to satisfy the needs of the populations and give color to the city.

### *4.2. Ecological Aspects of Urban Flora*

Urban forestry that integrates trees in rows increases both faunal and floral biodiversity by providing habitats for more than one taxon [43, 68, 69]. Such is the case, in Brazzaville, of epiphytes (ferns, orchids and strangler ficus, lichens, mosses), parasitic plants (fungi in part), especially hemiparasites

(*Loranthus* sp.) which find ideal conditions for development there [43]. The tangible consequence is the increase in floristic diversity, in addition to the fact that several of these taxa are very reliable bio-indicators at the bioclimatic and environmental level [43, 70]. About wildlife, besides serving as perches, trees are a source of food, breeding ground and nesting boxes for more than one species (insects, mammals, birds). The evolutionary duality of plants and animals reflects the importance of this pooling of intrinsic values of each unit to sustain life and ecosystem balances [6, 7, 32, 38, 43]. The ecological aspects of urban forestry and particularly of avenue trees offer eloquent and accessible examples for the exploitation of pedagogical notions (introduction to ecology) that would require expensive travel to rural areas [10, 31, 71].

Notwithstanding the benefits, that everyone is likely to appreciate, other more subtle and distinctly interesting products, and beyond the boundaries of the geographic area covered, are provided to the population and humanity [8, 9, 23, 63, 70]. At the population level, the most tangible benefits are expressed in terms of daily satisfaction of trophic appetites, primary health care and even support of the socio-cultural base and energy source. Conversely, the intangible benefits influence the psychic, mental health and well-being, the resilience of the city by combating the heat islands generated, and finally engender a local microclimate by regulating the region's climate system [5, 11, 27, 34, 36, 72-75] Note that addressing climate change requires carbon sequestration via plant metabolic processes. In order to optimize the response to climate change, stand renewal is necessary because the needs of a senescent individual are significantly lower than those of a young individual, in terms of balance. The ecological efficiency of carbon sequestration will only be satisfactory if the level of transformation of all woody parts of the trees is raised. Thus, traditional craftsmanship as practiced cannot be an adequate and sustained solution in the long term.

### 4.3. Degradation of Living Capital

Urban incivism is a phenomenon that causes the degradation of living capital and avenue trees are not spared. To supply the artisanal workshops, in urban areas, in addition to the trees that are victims of natural weathering, fires are lit at the base of the trees or even girdled as a result of intensive bark collection [44]. Thus, phytotherapy focuses on *Peltophorum pterocarpum, Mangifera indica, Senna siamea, Terminalia superba, Terminalia catappa, Millettia laurentii*. As for handicrafts, in addition to *Acacia auriculiformis* and *Acacia mangium*, we find the entire floristic cohort underlying phytotherapy. These wrongdoings reduce the urban forest cover, while underpinning the socio-cultural base and providing substantial income to the populations holding the empirical knowledge [23, 44, 66, 70, 76, 77]. The street trees of the city of Brazzaville are, without exaggeration, suppliers of raw materials to urban craftsmen and phytotherapists. The consequences of the mega-management of street trees in Brazzaville by skilled services coupled with the incivism of the population have led to the extinction of *Spathodea campanulata, Schizolobium parahybum, Jacaranda mimosifolia, Aleurites moluccana, Hymenaea courbaril, Samanea saman*, in the Brazzaville urban space [63]. For lack of renewal of stands and medicinal power of bark, several taxa currently present as avenue trees are physiologically and morphologically ill-conformed; and among these *Peltophorum pterocarpum, Senna siamea, Terminalia catappa, Terminalia superba, Millettia laurentii* and *Mangifera indica*. This trend would be amplified by the illicit introduction of several species of neotropical palms in alignment, to the detriment of woody plants, without distinction of origin and socio-economic expectations.

### 4.4. Influence of Ecosystem Services on Phytodiversity

The social, economic and environmental functions that forest formations provide, regardless of their location and extent, are not lost on urban alignment trees [4, 26, 33, 66, 77, 78]. The traditional knowledge associated with plants is the basis for the specific consideration and devotion expressed by the riparian's, who find their account there. In addition to this demand for empirical or even bookish knowledge, the impoverishment of the majority of city dwellers is one of the determining factors in the choice of trees for urban development [23, 43, 70, 79, 80]. Indeed, urban forestry, and in particular street trees, are the basis of the socio-ecological and landscape values that govern the preferences of the actors [79, 81-83]. In terms of ecosystem services, provisioning and regulating services are the focus of people's attention, both in a global reflection on needs, and considering the level of education of informants. The difficulty in satisfying the demand of each of the actors places the managers of the city in front of their responsibility to find urban planning policies that can satisfy the desires of the residents and other users.

### 4.5. Perception of the Avenue Tree in the City

The paving of the arteries, which is secular in Brazzaville, has still not met the expectations of the population. There are many reasons for this and the most relevant one would be associated with the diversity of interests of the social strata. This activity, which is the responsibility of the municipal services, lost its amplitude in the independence years (1960) and becoming sometimes the nightmare of the city managers. The tropical tree by its growth rate of about 1cm/year is ineluctably a partial measure of time, under natural conditions [84]. Thus, individuals inventoried in the city center, the site of the development operation, are highly senescent with dbh ≥ 70 cm. These taxa (*Mangifera indica, Terminalia catappa and Peltophorum pterocarpum* or even *Millettia laurentii*), which are very weakened, are the cause of several incidents affecting people and their property [80, 85-87]. As a result of ever-increasing human activity, the urban forest cover is in full regression, leaving several arteries exposed, such as the avenues of the Cité des 17, Moukoukoulou Street, and the street leading to the Church of Jesus Resurrected, in Plateau des 15 ans, and the avenue Docteur Blachet in Mpila which were once very flamboyant with *Delonix regia, Peltophorum pterocarpum, Schizolobium parahybum, Jacaranda* *mimosifolia* and *Spathodea campanulata*. The current resumption of paving of arteries, mainly based on *Terminalia mantaly, Corymbia* sp., *Acacia auriculiformis, Acacia mangium, Cananga odorata, Polyalthia longifolia*, awkwardly carried out, without observing the conventional minima, attracts more discontent than appeasement. The lack of respect for the rules coupled with the poor choice of taxa (lack of knowledge of the plant) would be the reason for the negative effects noted on the urban roads. In addition, the absence of an urban tree policy and national standards on the maintenance and replacement of taxa or even rejuvenation of the stand would be factors that negatively aggravate the perception of populations [88-91]. Finally, the anthropic action associated with the collection of bark affects the metabolism of taxa and their general morphology, resulting in deformity of the subjects and sometimes-even death on foot [44]. This set of facts negatively impacts the desired landscape value of avenue trees with respect to riparian populations and users.

As for the taxa that one would qualify as accidental in alignment, their existence is the work or the result of anarchic occupation of public space by the residents. Thus, in an insidious way, a useful reserve is constituted, while the community benefits from the indirect fallout. Without being exhaustive, let us mention *Spondias mombin*, *Ficus* sp., *Cocos nucifera, Tamarindus indica, Persea americana, Pentaclethra macrophylla* and *Ricinodendron heudelotii*, whose primary purpose is to support provisioning services (food, phytotherapy, wood-energy) and shading for regulating services, the bulk of which is almost imperceptible.

# 5. Conclusion

Urban arboriculture in Brazzaville is constantly decreasing in coverage, despite the fact that it increases urban floristic and faunal diversity by providing habitats. Stemming this situation requires normative and regulatory acts on the place of trees in the urban environment and in development policies. However, its predominantly exotic composition does not enhance the local flora and the expectations of the population, such as the pedagogical significance and the conservation or reserve of taxa. Avenue trees provide ecosystem goods and services (tangible and intangible), the importance and appreciation of which are mixed depending on the social strata. The expectations of the populations would be summarized in the desiderata and social situations of the residents, hence the difficulty of satisfying or even accessing the myriad of requests.

The poor conduct of urban development, and in particular of avenue trees, leads to a negative perception of them by the population. This feeling of rejection is exacerbated by the pollution and disservices caused to roads and urban infrastructures. Finally, the study offers tools that are assets for city managers in taking into account the issue of trees and ecosystem services in the reflections and development of policies on urban development.

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